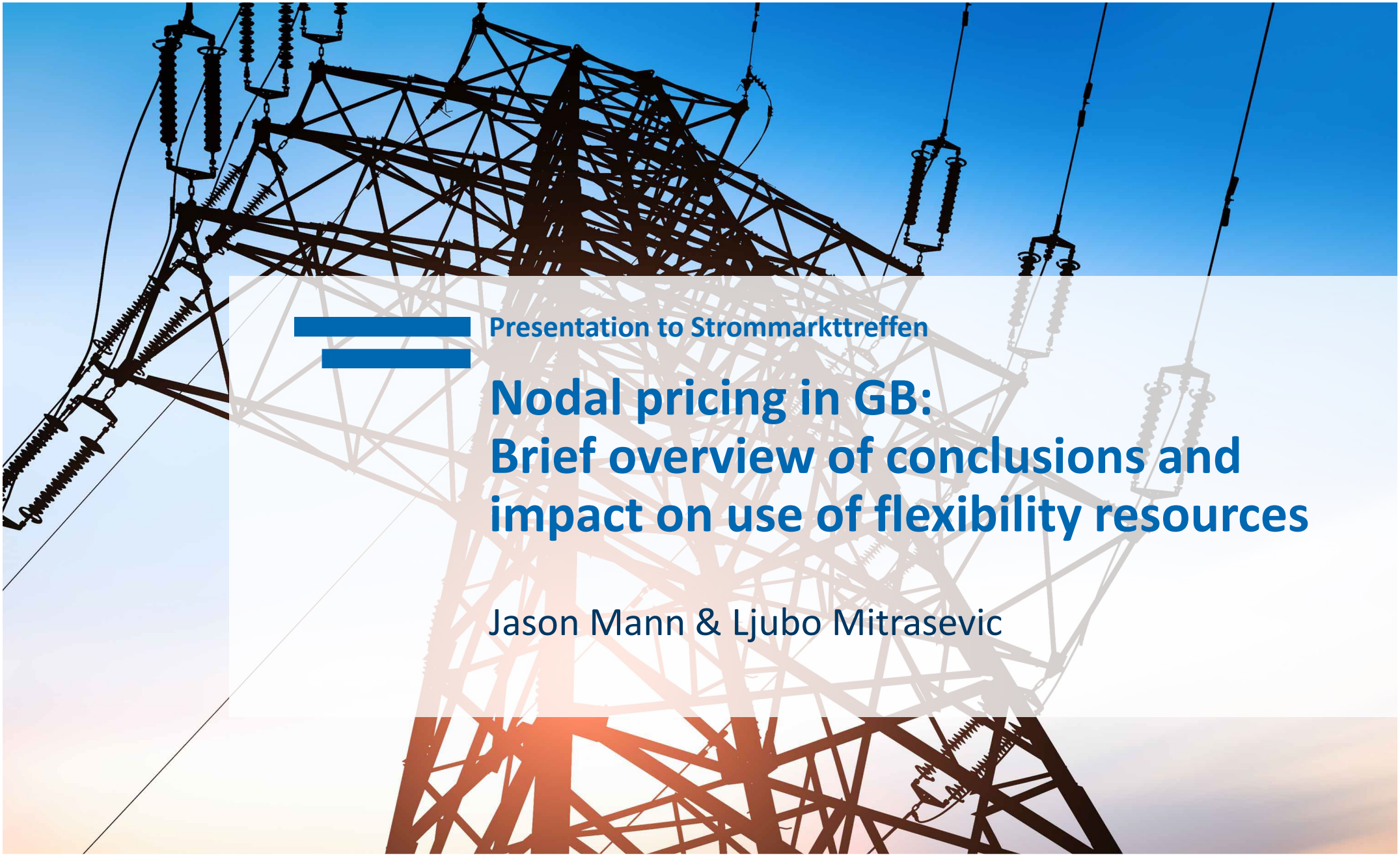


Presentation to Strommarkttreffen

Nodal pricing in GB: Brief overview of conclusions and impact on use of flexibility resources

Jason Mann & Ljubo Mitrasevic

FTI CONSULTING™

2 June 2023

Introduction to the FTI Team

FTI CONSULTING™

FTI's global team have advised regulators and industry around the world on matters of market design, regulation and pricing for over 25 years

North America

Major role in developing the market design in most US markets:

- **Renewables integration** – Developing market design for **MISO, PJM, CAISO, ERCOT**
- **Location**-based redesign for **CAISO** and **Ontario's** transition to **LMPs**
- **Reforming the Energy Vision (REV)** – Advised on regulatory overhaul to encourage clean and more efficient power system

Europe

Leading role in developing market models combining low-carbon, capacity and flexibility support:

- **Capacity mechanisms –** Design & impact assessment in > 14 European countries
- **Investment framework** – Developed unified mechanism across adequacy, flexibility and clean energy
- **German & Dutch TSO regulation** – developed regulatory systems to alleviate CAPEX/OPEX bias, reduce system operation costs and absorb renewables

GB & Ireland

- **Wholesale market design** – Assessment of locational wholesale electricity market design options for Ofgem
- **Net Zero Market Reform** – For NGESO, examined changes to GB electricity market design that will be required to achieve net zero
- **Hydrogen** – Advisor on options for hydrogen storage market
- **RIIO-2 price control** – Strategic advice and support to National Grid on RIIO-2 price control design framework and business plan submission
- **SO regulatory regime** – Advised NGESO on how to incentivise and remunerate external costs for the newly separated SO
- **Setting retail price cap** – Led analysis of impacts of setting price cap on retail energy tariffs

GCC

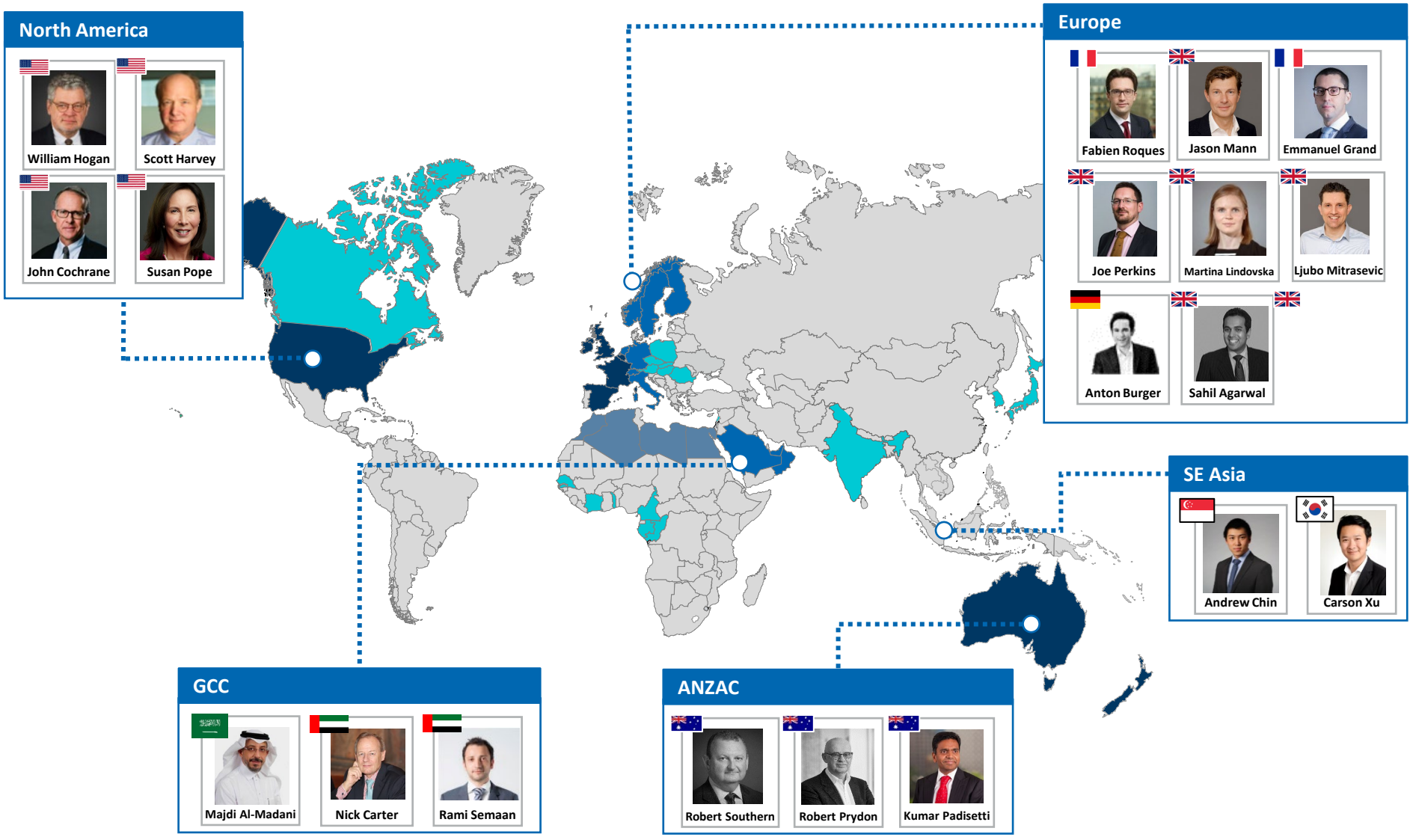
- **Final user tariffs** for the Abu Dhabi power and water sectors, Structured on a revenue requirement allowance basis through the application of periodic price controls
- **Use of system tariffs** for the UAE TRANSCO company for power and water sector – TUoS and Abu Dhabi DUoS charges
- **Final user tariffs** for the KSA Water sector for WERA

Australia & New Zealand

Lead consultant in Post-2025 market design reforms:

- **Capacity adequacy and ancillary service mechanism reforms** for **ESB**
- **Day-ahead markets reforms** for AEMO
- **Regulatory investment tests for AEMO** – Reviewed test practices in Europe and the US, identifying potential options for effective future models in Australia

In the energy sector, FTI has global reach and world-leading expertise in electricity market design and regulation



Our experience and capabilities
Market design: Great Britain – Review of electricity market arrangements

Jurisdiction

Key clients

ofgem

nationalgridESO

octopusenergy

Department for Business, Energy & Industrial Strategy

Duration

2020 – 2023

FTI's global team of world-leading experts are the lead advisors to GB policy makers in their current review of energy market arrangements, focusing on market designs for a renewables-dominated power system.

MARKET DESIGN IN THE CONTEXT OF NET ZERO[1,2]

- FTI supported **National Grid ESO** to explore how GB electricity markets must evolve before 2035 to support the **transition to renewable generation** and Net Zero by 2050.
- This involved assessing a **range of market design options** and assisting NG ESO to develop **recommendations for reform**.
- FTI's qualitative and quantitative analysis included the advantages and disadvantages of varying levels of **locational granularity** and alternative **dispatch mechanisms**.

ASSESSMENT OF LOCATIONAL PRICE SIGNALS[3]

- FTI was commissioned by Octopus Energy to understand, quantitatively, the potential benefits of more granular locational pricing in the wholesale market and the impact on consumers.
- FTI modelled the impact of reduced congestion, changes in wholesale prices, improved siting decisions and more efficient dispatch between 2022-2035.

GB WHOLESALE MARKET REFORM[4]

- FTI currently supports **Ofgem** in evaluating the **costs and benefits** of transitioning to an electricity market design with **greater local granularity in the wholesale electricity market** compared to the current national pricing model.
- This involved assessing the benefits of moving to either a **zonal or more granular nodal approach**.
- The team conducted a detailed assessment of the **socio-economic welfare impact** of greater locational granularity of prices on different regions.
- Our assessment was also **informed by the experiences and expertise of various stakeholders via frequent workshops**, including the System Operator, market participants, investors and consumers.

ALTERNATIVE ENERGY MARKETS PROGRAMME

- FTI Consulting was engaged by the Department for Business, Energy & Industrial Strategy ("BEIS") and the flagship Alternative Energy Markets ("AEM") Programme to support innovative demand-side flexibility propositions in a future energy system.

Key Lessons

- Managing volatility and uncertainty is the key design issue in a renewables-heavy power system. The market design needs to first ensure available resources are deployed optimally and second deliver the needed investment in renewables generation, networks, storage providers of flexibility as well as new specialist ancillary services such as inertia.

***Public presentation materials**: **(1)** Net Zero Market Reform webinar, 17/01/2022, (link); **(2)** Net Zero Market Reform webinar, 18/01/2022 (link); **(3)** GB Locational Pricing – A framework for analysis of benefits and some initial results, 6/05/2022, (link); **(4)** Locational Pricing Assessment workshops, 26/05/2022 – 20/10/2022 (link).*

Our experience and capabilities
Market design: Australia Post-2025 market design

Jurisdiction

Australia

Key clients

ESB

AEMO

AEMC

AER

Duration

2017 – 2022

Over several years, FTI's global team of electricity market design experts has supported the Australian energy market bodies on a sequence of electricity market reforms as Australia rapidly transitions towards a renewables-based electricity system.

LONG-TERM INVESTMENT SIGNALS FOR RESOURCE ADEQUACY[1]

- FTI supported the Australian Energy Security Board (ESB) in developing **long-term market frameworks to deliver resource adequacy** in a network increasingly dependant on variable renewable generation.
- The team **assessed possible reforms** to existing mechanisms along with the **merits of introducing alternative options**.

OPTIONS TO VALUE, PROCURE AND SCHEDULE ESSENTIAL SYSTEM (ANCILLARY) SERVICES[2]

- Supported the ESB in developing **options to value, procure and schedule essential system (ancillary) services**, including inertia and frequency management, as synchronous thermal generators are replaced by inverter-based renewables.
- This involved **evaluating several procurement mechanisms** and **developing a roadmap for reform** for each service.

ASSESSING FUTURE COST OF NETWORK CONGESTION[3]

- Advised the Australian Energy Security Board on the **impact of transmission congestion** in the electricity market.
- **Modelled the impact of alleviating transmission constraints** on system costs and the generation mix.

DAY-AHEAD MARKETS

- Advised the Australian Electricity Market Operator on the various options being put forward for the **introduction of a day-ahead market** in the National Electricity Market.
- This work supported AEMO in forming a view as to the workability of each option and its overall recommendation.

TRANSMISSION REGULATORY FRAMEWORKS

- FTI compared the existing **Regulatory Investment Test for Transmission** (RIT-T) to international equivalents, **identifying lessons and options for effective future models in Australia**.
- This also included a review of the calculation of retail tariffs (covered on page 34, under our tariff design experience)

INTEGRATION OF DISTRIBUTED ENERGY RESOURCES[4]

- Supported the Australian Energy Security Board in **assessing the cost and benefits** of introducing technical standards to integrate **residential distributed energy resources** in the NEM and enable dynamic export management.
- Supported the Australian Energy Regulator in **developing a regulatory framework** to support the introduction of **dynamic management of residential distributed energy resources**, including solar and batteries.

Key Lessons

Market designs implemented when electricity systems were dominated by synchronous thermal generation are not compatible with a renewables-based system - new designs must be developed and implemented to manage increased volatility and uncertainty.

- Ensuring sufficient provision of ancillary services, which often historically have been provided as a by-product of thermal generation (especially inertia), and flexibility (of both generation and demand) are critical aspects of designing a renewables-based energy system and must be valued appropriately.
- Robust assessment frameworks to identify and approve cost effective investments are required to develop and maintain an efficient and reliable renewables-based system.

***Public presentation materials**: **(1)** Resource Adequacy Mechanisms in the NEM, 16/07/2020, (link); **(2)** Essential Services in the NEM, 14/08/2020 (link); Forecast Congestion in the NEM, 05/08/2021, (link); DER Interoperability Assessment Framework, December 2021, (link).*

Approach and overall assessment results

FTI CONSULTING™

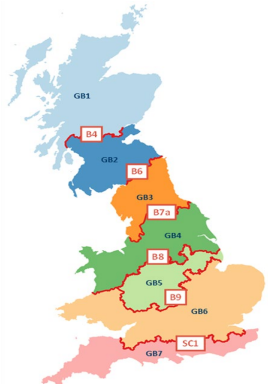
In response to these emerging issues and Net Zero ambitions, Ofgem has commissioned FTI to develop a detailed locational GB power market model…

National

Uniform price clears across entire market

GB Germany

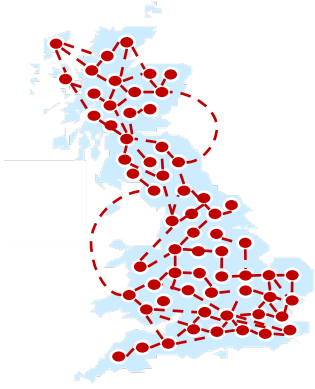
Zonal



*System divided into **seven zones** with individual prices*

Australia Sweden Norway Italy

Nodal



*System divided into **c.850 "nodes"** with individual prices*

USA New Zealand Canada (Ontario) Singapore

1 Power market model

Detailed fundamentals power market model,

PLEXOS BY ENERGY EXEMPLAR

2 Transparent input sources

- Publicly available info (notably FES 2021, ENTSO-E)
- **More than 50 bilateral engagements**
- model t**hree energy scenarios** based on the FES:

nationalgridESO

entsoe

3 Stakeholder engagement

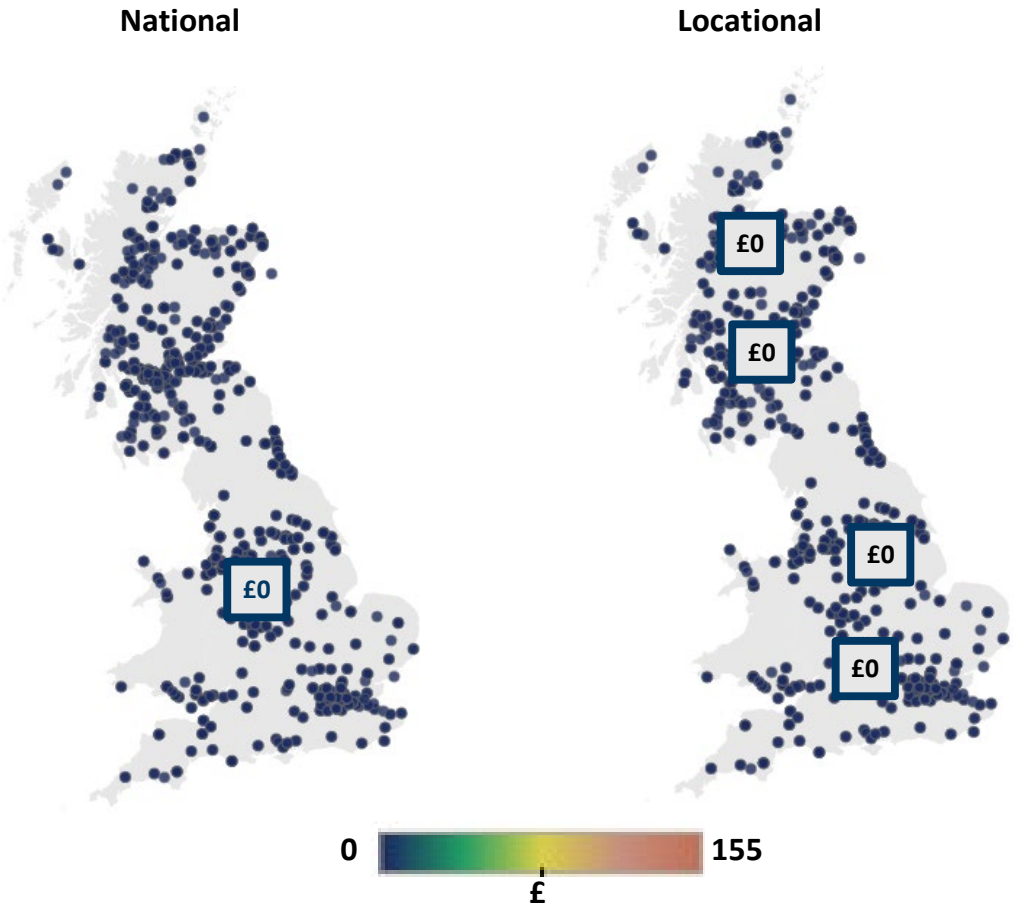
- **150 industry stakeholders** (**3 workshops to-date**)
- 5 **direct engagements with BEIS/DESNZ**

Department for Business, Energy & Industrial Strategy

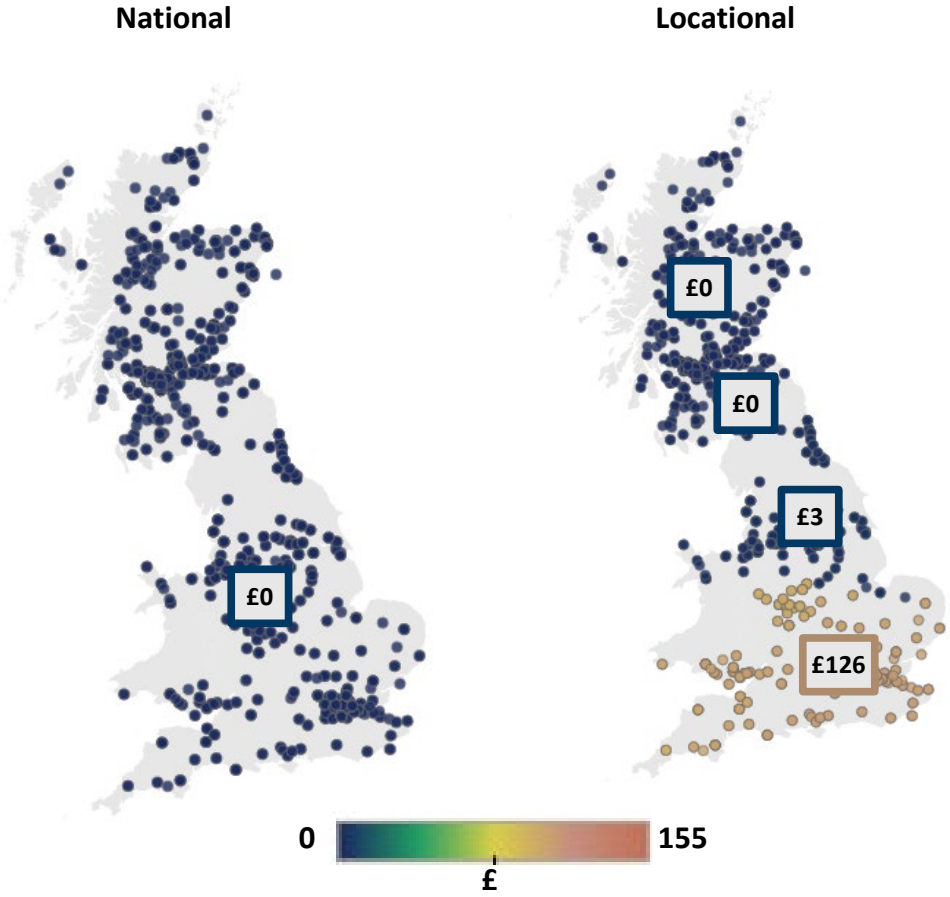
… our full results will be presented in two Ofgem workshops on 6 June in London and mid-June in Glasgow

In our assessment, wholesale electricity prices vary under each market design – we show example hours below when wind output is very high…

1 ***Example of a very high wind hour <u>across GB</u> (29th Sept 2040 – 12:00)***



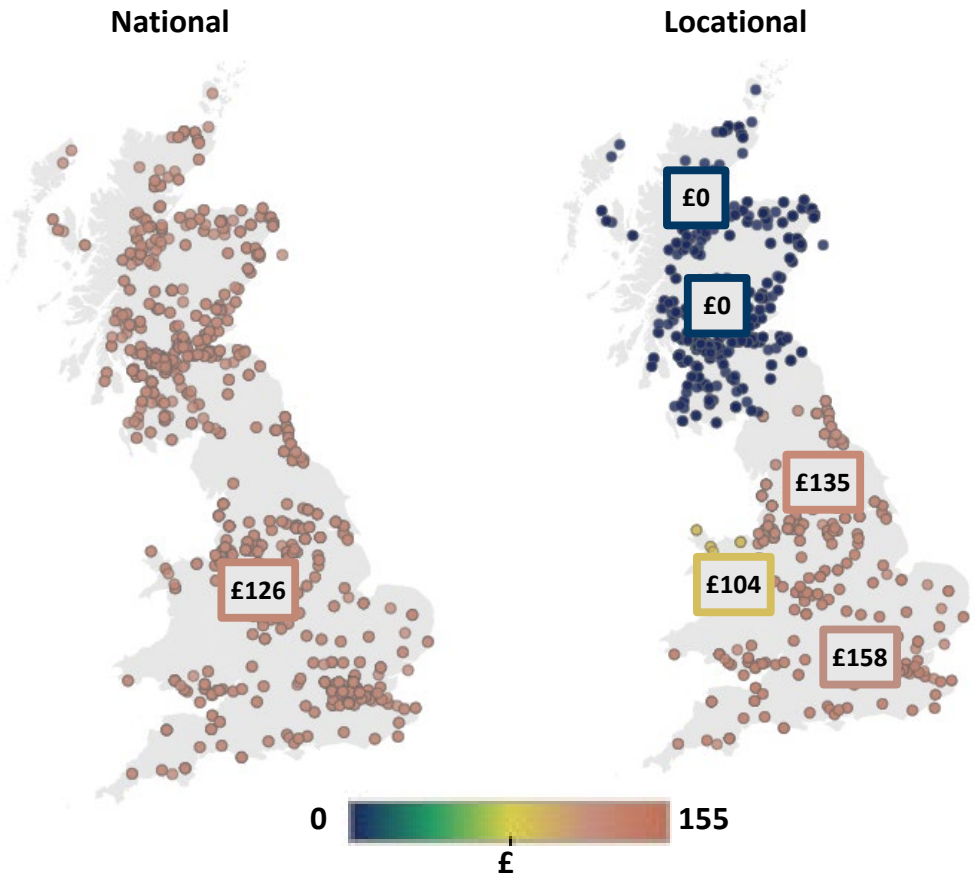
2 ***Example of a very high wind hour <u>in Scotland and northern England</u> (10th Dec 2040 – 17:00)***



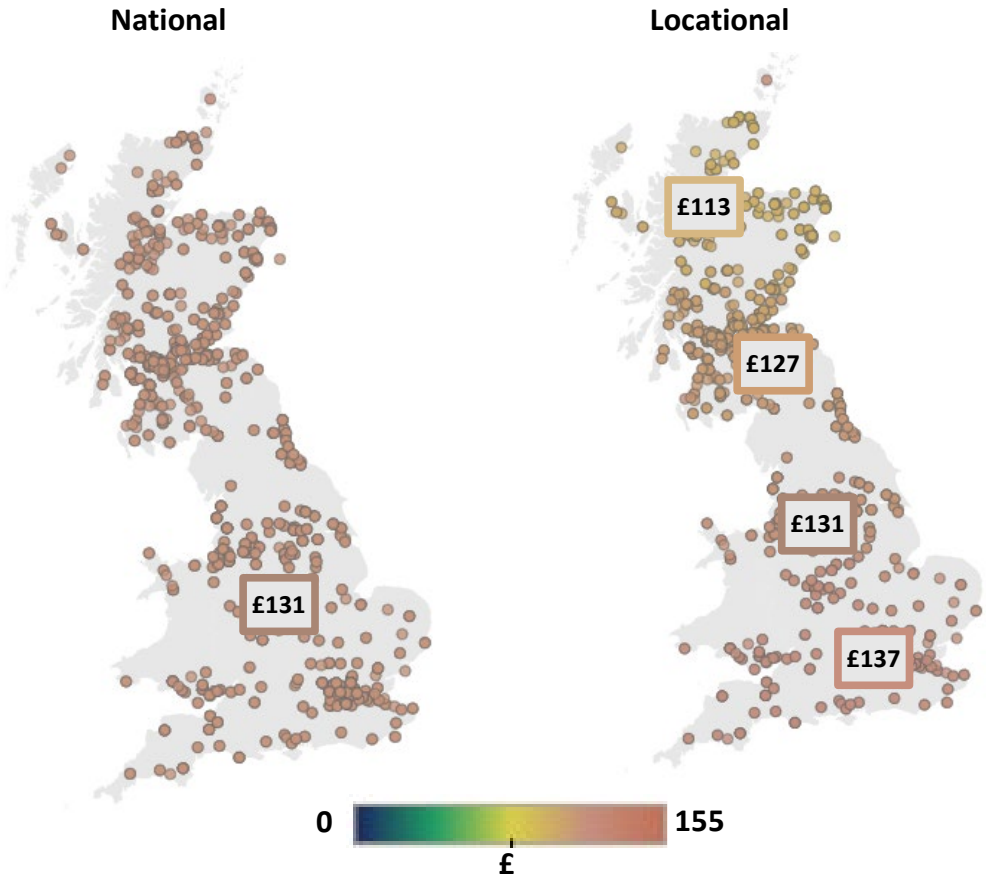
Source: FTI Consulting

… and also show example hours when wind output is lower

1 ***Example of a moderately high wind hour in Scotland and northern England (17th Jan 2040 – 5pm)***



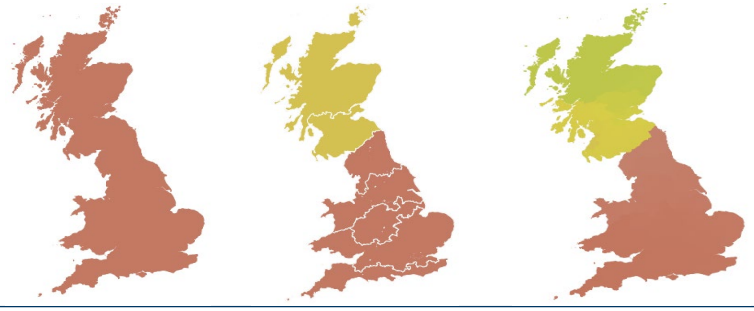
2 ***Example of a low wind hour in Scotland and northern England (27th Feb 2025 – 8am)***



Source: FTI Consulting

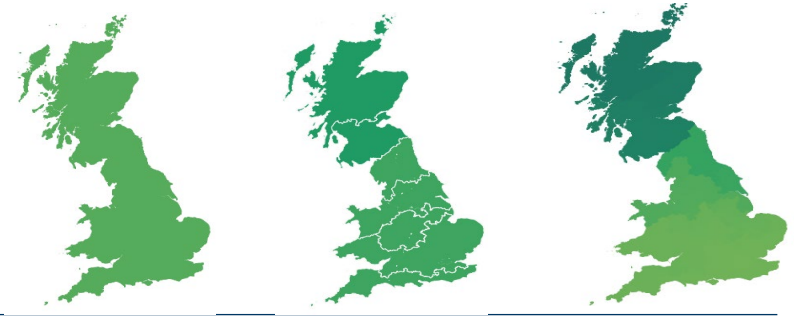
Average wholesale power prices across the three market design options are influenced both by 'macro' trends and by the locational granularity

2025 – Load weighted annual average wholesale prices, £/MWh



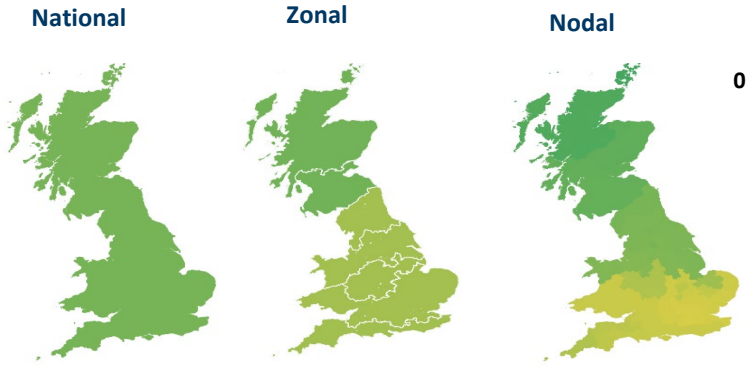
	National	Zonal	Nodal
LtW (NOA7)	£72.60	£47.40 - £79.30	£37.40 - £81.30
LtW (HND)	£72.60	£47.50 - £79.40	£37.40 - £81.40
SysTr (NOA7)	£75.00	£53.90 - £76.90	£42.90 - £80.10

2030 - Load weighted annual average wholesale prices, £/MWh



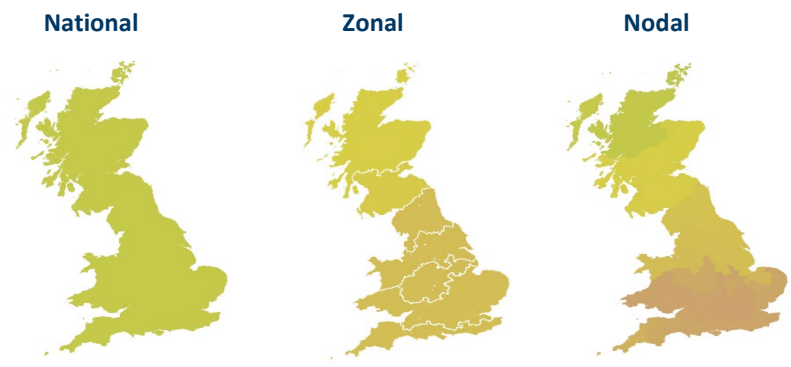
	National	Zonal	Nodal
LtW (NOA7)	£23.50	£17.40 - £29.20	£13.80 - £31.00
LtW (HND)	£23.50	£21.00 - £24.90	£18.50 - £27.40
SysTr (NOA7)	£25.70	£20.40 - £28.20	£17.20 - £31.00

2035 - Load weighted annual average wholesale prices, £/MWh



	National	Zonal	Nodal
LtW (NOA7)	£34.10	£31.80 - £37.80	£24.90 - £43.10
LtW (HND)	£34.10	£31.10 – £37.00	£25.70 - £42.30
SysTr (NOA7)	£29.90	£25.80 - £31.40	£22.80 - £35.00

2040 - Load weighted annual average wholesale prices, £/MWh

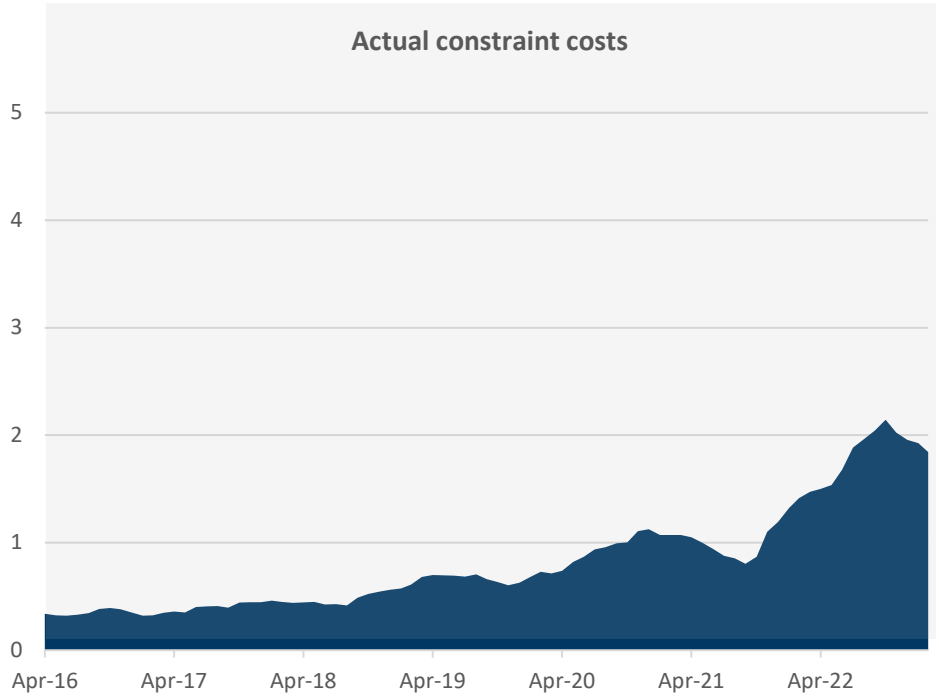


	National	Zonal	Nodal
LtW (NOA7)	£50.90	£45.40 - £50.90	£37.0 - £58.70
LtW (HND)	£50.90	£43.00 - £48.90	£37.50 - £56.40
SysTr (NOA7)	£30.20	£27.60 - £32.20	£21.20 - £38.40

- Moving from national to zonal and nodal widens the range of prices observed, as Tx congestion and (in nodal design) losses are reflected in wholesale price
- The price spread is generally greater for Leading the Way than for System Transformation due to the higher demand, different technology mix, greater penetration of variable renewables and two-way assets (interconnectors and batteries)

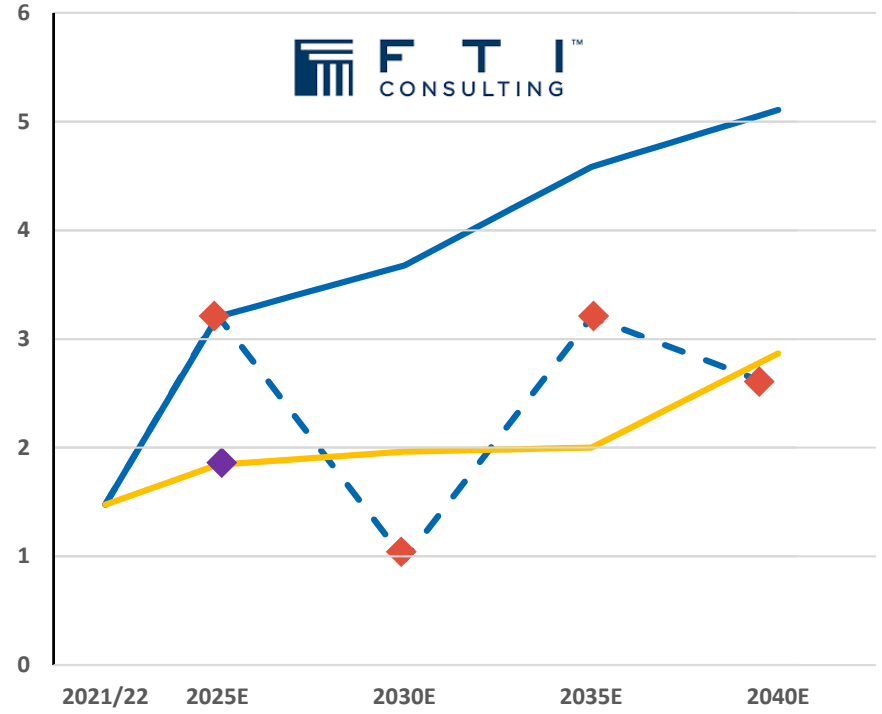
The GB constraint costs increased significantly since 2010 and we forecast a trend to continue under the current market design

Actual constraint cost, 12m rolling average, £bn



***Source**: System balancing reports, NG ESO (link).*

Constraint cost estimates, 2018-2040, £bn

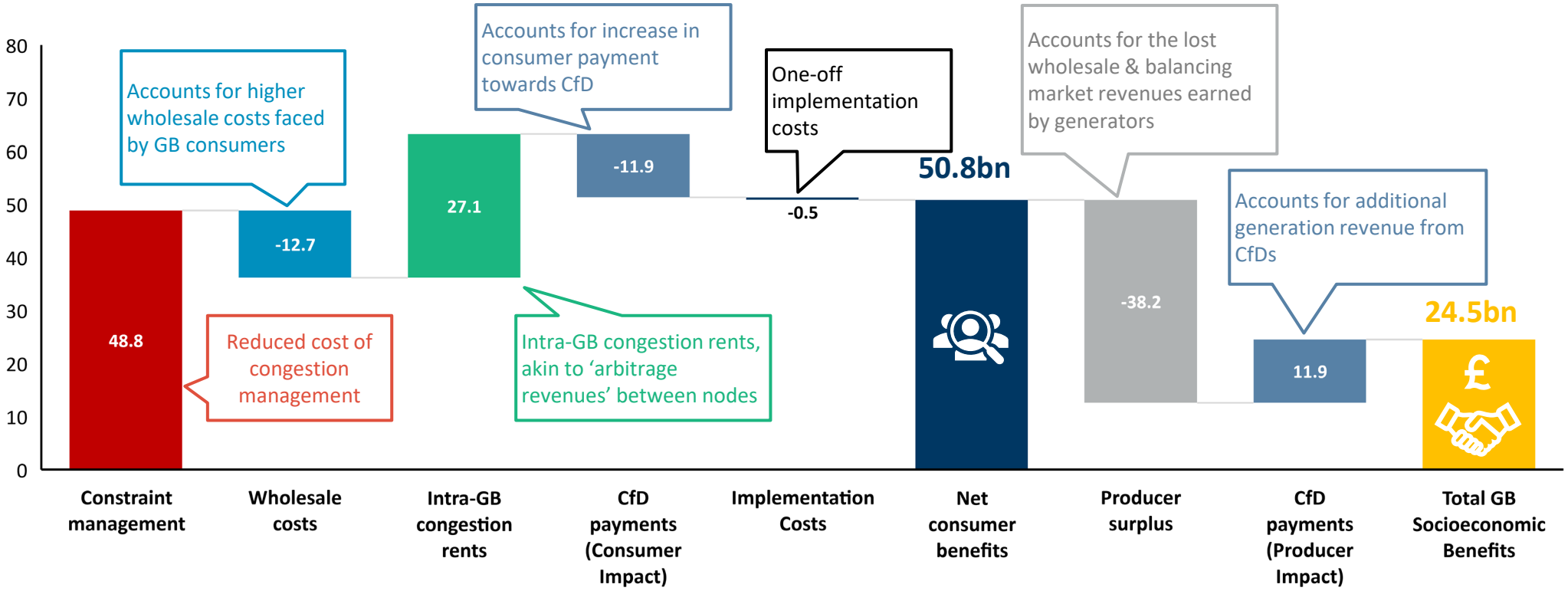


Actual costs
FTI estimates under NOA7
FTI estimates under NOA7 incl. HND
FTI Estimate SysTr

When aggregating the impact of locational pricing in each hour, our assessment shows significant benefits to consumers over the entire modelling period

Breakdown of consumer surplus and welfare (£bn, Present Value 2025-40, Nodal – National, Leading the Way NOA7)

Price basis for NPV estimation is 2024.

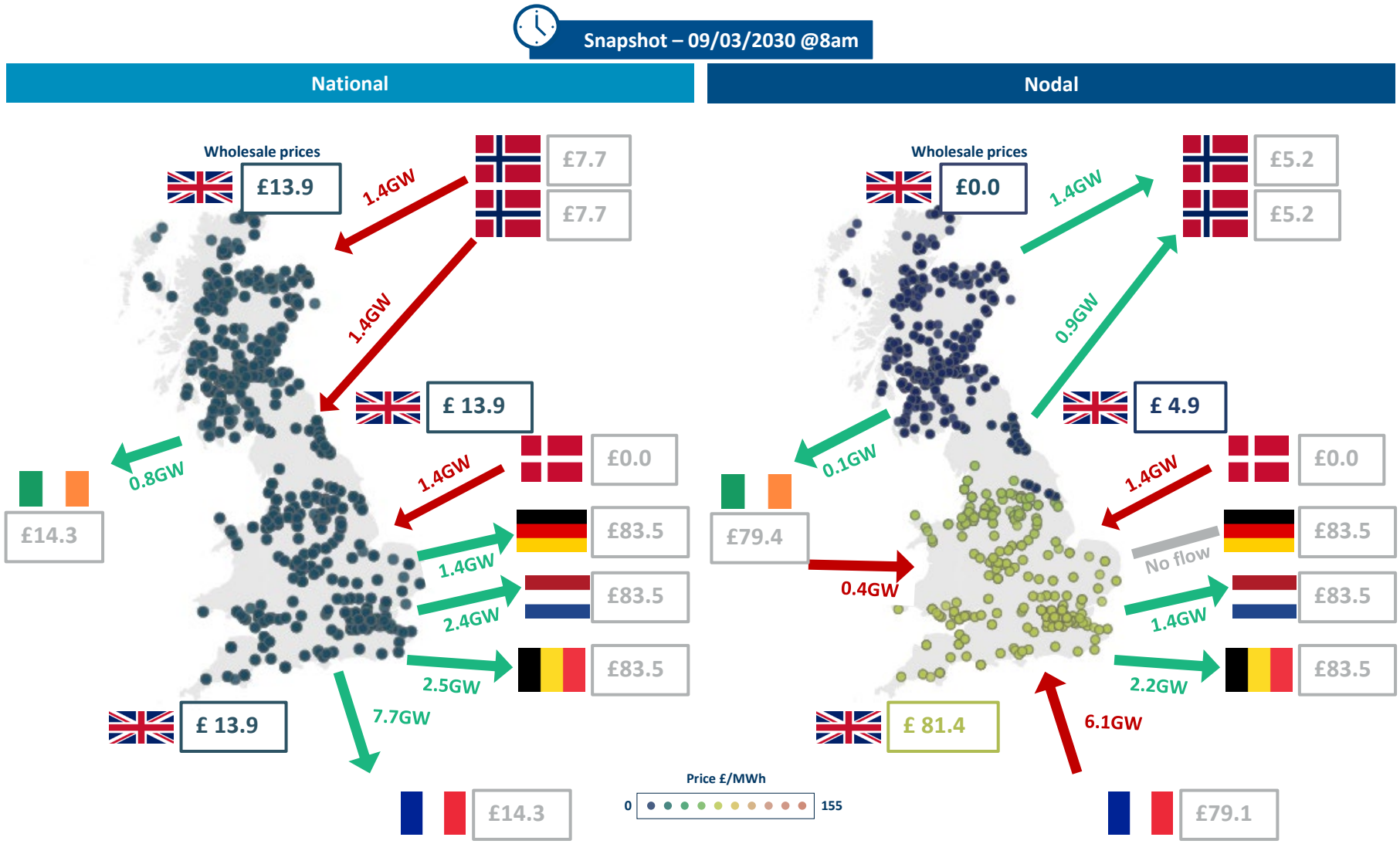


Source: FTI Consulting

Impact on flexibility assets

Nodal pricing would change interconnector flows between GB and connected countries

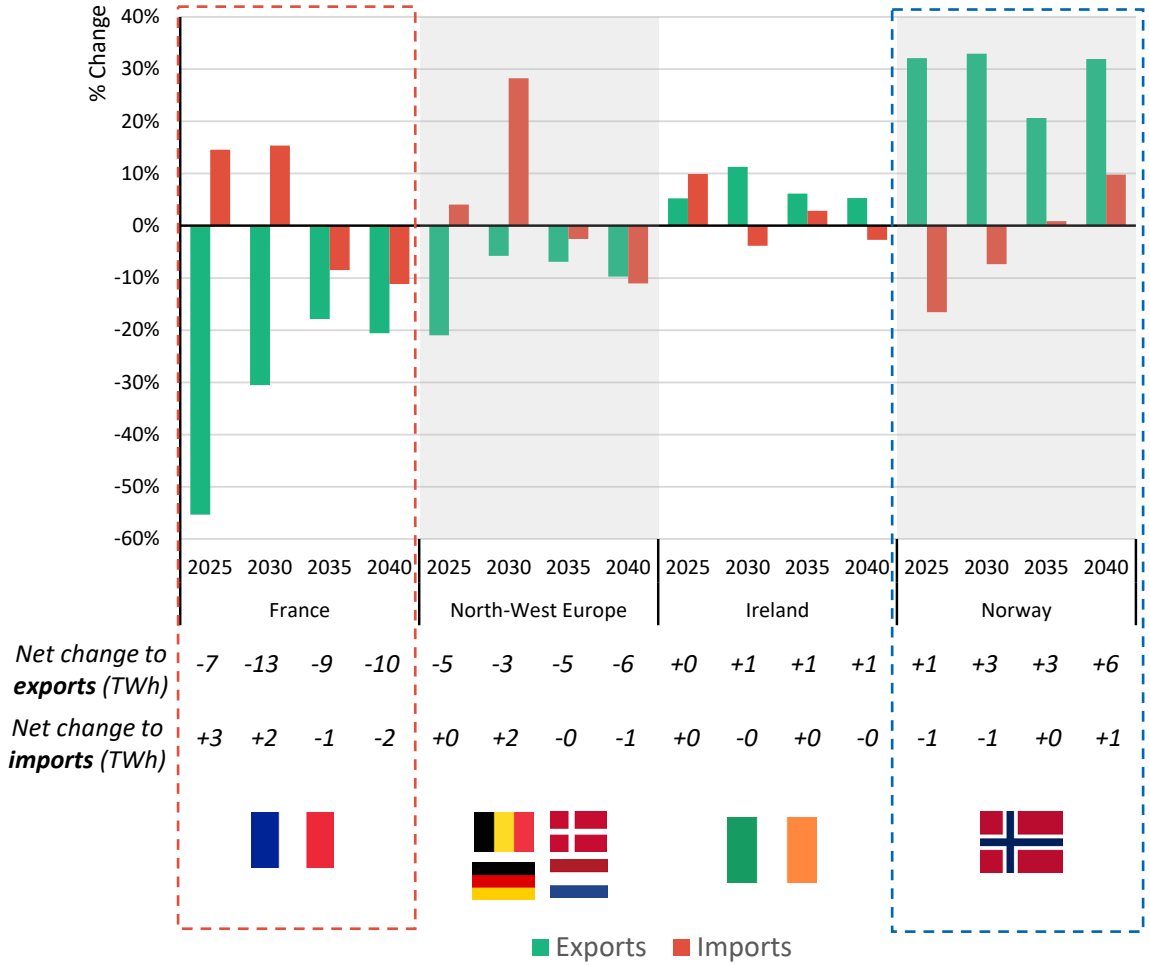
Example of the impact of nodal pricing on interconnectors



Source: FTI Consulting
Note: We follow ENTSO-E's methodology model which includes consideration of the transmission network between NI and ROI

Over a year there are significant differences in interconnector flows, particularly between GB and Norway and between GB and France

Change in interconnector flows (nodal relative to national)



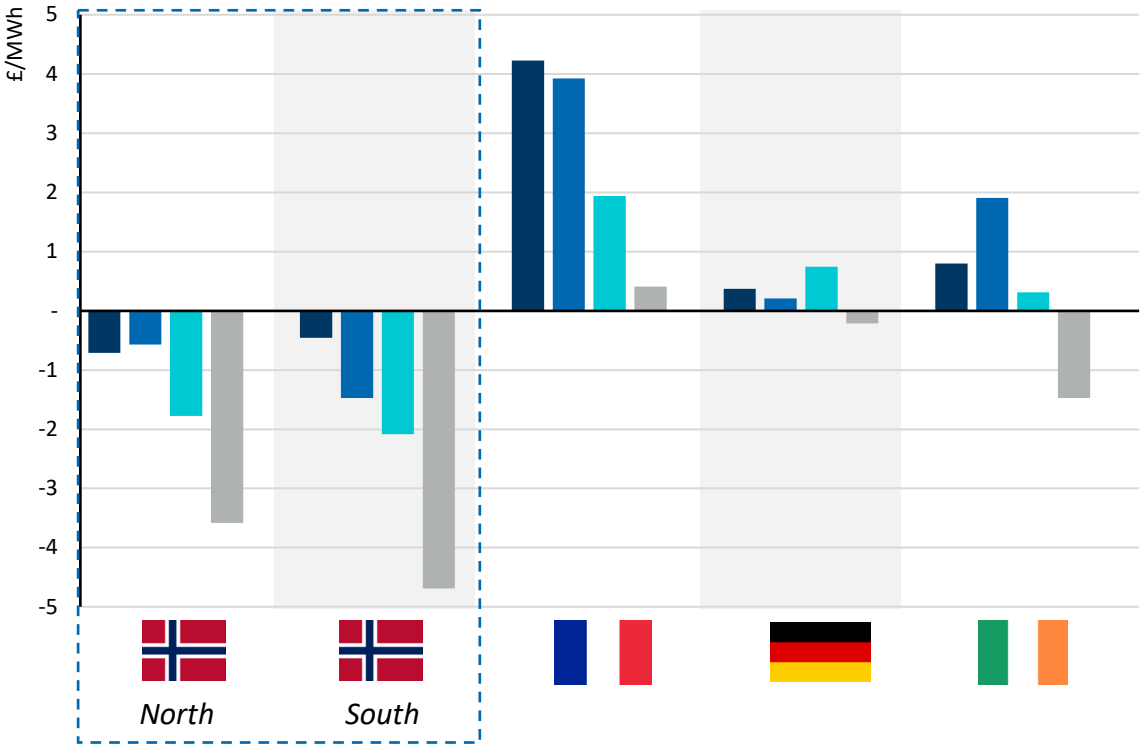
- Large increase in exports to Norway due to the location of the landing point of the two interconnectors.
- Nodal prices account for the value of congestion and **allow surplus wind generation to be exported that otherwise would be constrained off**

- The opposite effect occurs in interconnectors to France, where there is high exports under the current market design.
- Nodal prices limit exports, and, indeed, imports would displace plant that is currently constrained on in GB market…
- Reduced flows in latter part of forecast period as a result of greater price convergence between South England and France.

Source: FTI Consulting

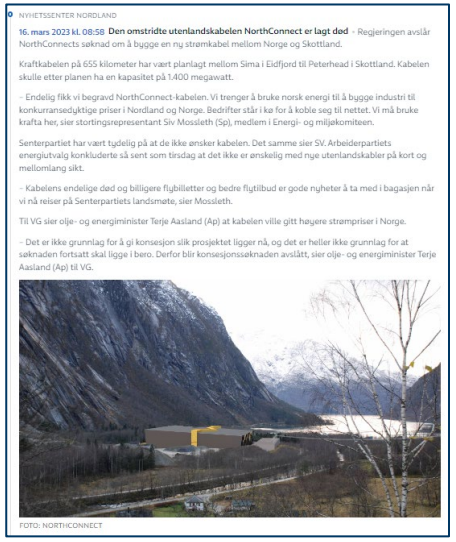
Changing interconnector flows impact prices in neighbouring countries…

Change in connected country prices



Source: FTI Consulting

- With nodal pricing, the increase in exports to Norway leads to a decrease in Norwegian wholesale prices…
- … could impact political narrative in Norway.



NYHETSSENTER NORDLAND

16. mars 2023 kl. 08:58 **Den omstridte utenlandskabelen NorthConnect er lagt død** - Regjeringen avslår NorthConnects søknad om å bygge en ny strømkabel mellom Norge og Skottland.

Kraftkabelen på 655 kilometer har vært planlagt mellom Sima i Eidfjord til Peterhead i Skottland. Kabelen skulle etter planen ha en kapasitet på 1.400 megawatt.

- Endelig fikk vi begravd NorthConnect-kabelen. Vi trenger å bruke norsk energi til å bygge industri til konkurransedyktige priser i Nordland og Norge. Bedrifter står i kø for å koble seg til nettet. Vi må bruke krafta her, sier stortingsrepresentant Siv Mossleth (Sp), medlem i Energi- og miljøkomiteen.

Senterpartiet har vært tydelig på at de ikke ønsker kabelen. Det samme sier SV. Arbeiderpartiets energiutvalg konkluderte så sent som tirsdag at det ikke er ønskelig med nye utenlandskabler på kort og mellomlang sikt.

- Kabelens endelige død og billigere flybilletter og bedre flytilbud er gode nyheter å ta med i bagasjen når vi nå reiser på Senterpartiets landsmøte, sier Mossleth.

Til VG sier olje- og energiminister Terje Aasland (Ap) at kabelen ville gitt høyere strømpriser i Norge.

- Det er ikke grunnlag for å gi konsesjon slik prosjektet ligger nå, og det er heller ikke grunnlag for at søknaden fortsatt skal ligge i bero. Derfor blir konsesjonssøknaden avslått, sier olje- og energiminister Terje Aasland (Ap) til VG.

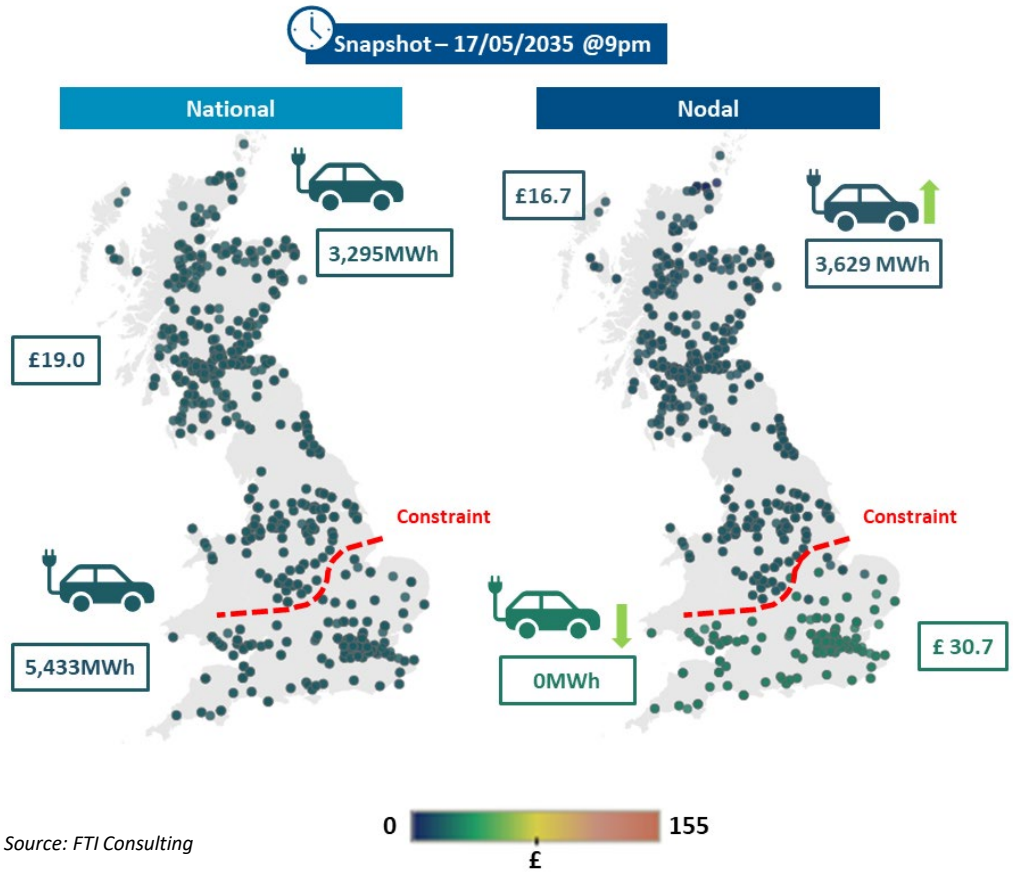
FOTO: NORTHCONNECT

"We finally got the NorthConnect cable buried. We need to use Norwegian energy to build industry at competitive prices in Nordland and Norway….We must use our strength here"
Siv Mossleth,
Norwegian MP Centre Party

Source: Norwegian Broadcasting Corporation

The timings of when consumers would charge their flexible EVs differs in a nodal market relative to the status quo

Snapshot of impact on EV charging[1]



Source: FTI Consulting

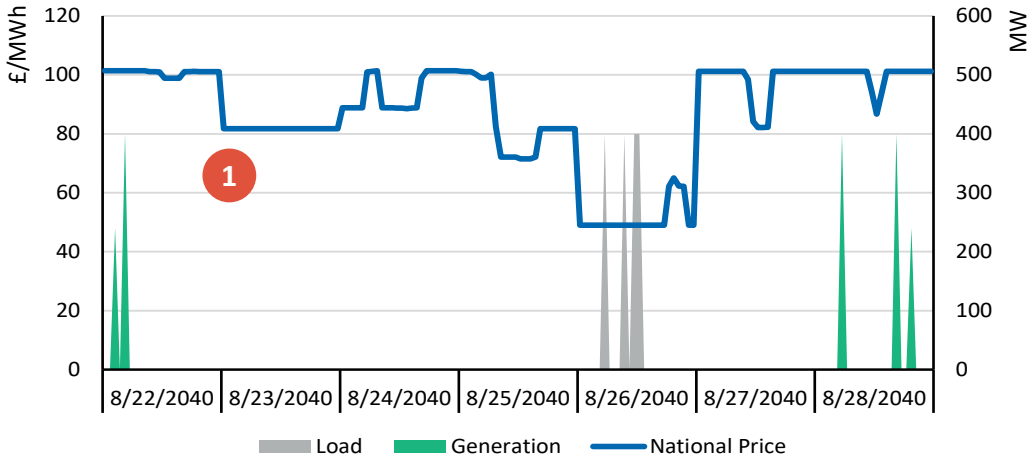
- In the FES, the use of EVs as a flexibility resource is expected to increase…
- … which could support system balancing under the efficient price signals…
- … or conversely, exacerbate consumer cost if wholesale price signals do not accurately reflect the needs of the system
- It is unclear if flexibility markets and/or smart active retailer solutions would be sufficient under the status quo market design

In 2035, the % of hours where flexible EV loads at each node were operating in an opposite manner in the nodal relative to national market runs (i.e. on in one and off in the other) was **28%**[2]

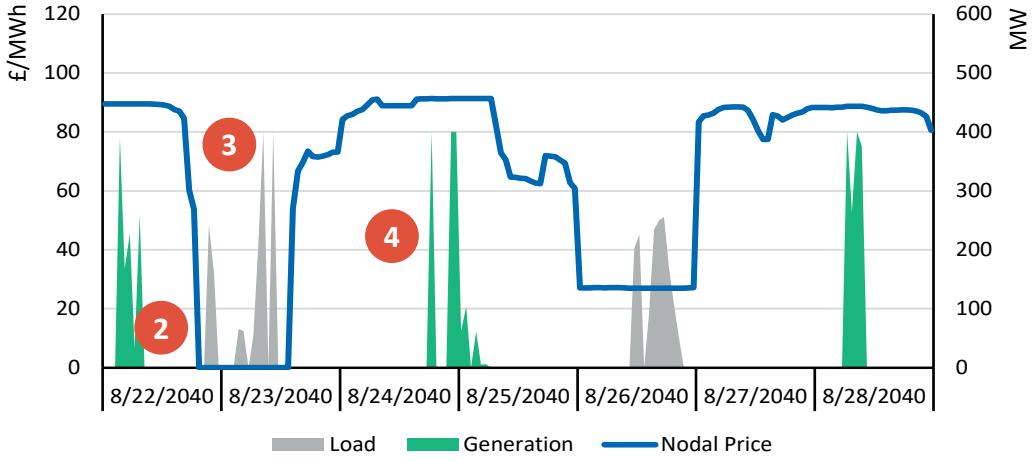
Note 1: DSR is impacted in a similar way to EVs in our assessment – we do not consider changes to both (1) overall demand and (2) resiting of demand
Note 2: This figure takes into account amount of EV capacity in each node so that it will only reflect changes to wholesale electricity market conditions and not capacity. There might be some other factors not related to wholesale prices that cause EVs to operate differently (e.g. local generator outages or extended periods of £0 prices) but we do not consider them to be material.

Locational pricing enables storage assets to better respond to the availability and need for power in the connected region

Hourly profile for Ardmore 4hr battery, National model (LTW), Aug 2040



Hourly profile for Ardmore 4hr battery, Nodal model (LTW), Aug 2040



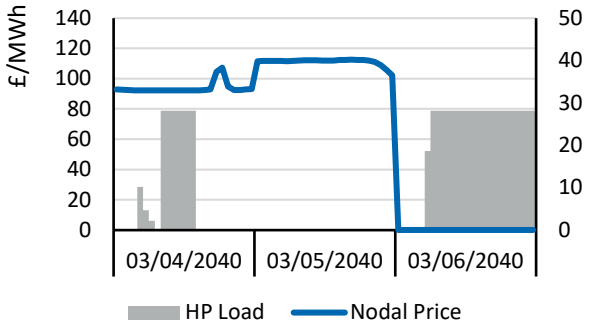
1. **Single national price is relatively stable, with insufficient price differential for battery cycling…**
2. **…but nodal pricing reflects there is an excess of supply in the local area, with some RES curtailment.**
3. **With correct price signal, battery is able to charge at low cost, reducing system curtailment in the process…**
4. **…and release the power to the system when local prices (and the need for power) rise in later hours.**

In 2035, the % of hours where batteries (in aggregate)[1] were operating in an opposite manner in the nodal relative to national market runs (i.e. charging in one and off or discharging in the other) was **23%**

Note: 1-2 hour duration batteries only. Unlike the analysis in EVs and Heat Pumps, we aggregate each unit of batteries as one object – this is because our market modelling software might treat different battery units indifferently on occasion (when conditions are equal) leading to arbitrary decisions on which battery should generate and/or consume

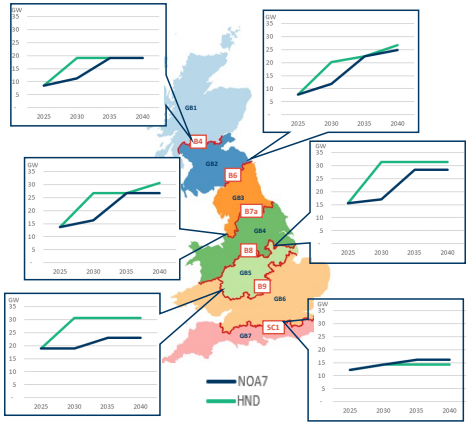
Our analysis encompasses various effects and impacts that may arise from different market design options.

Heat Pumps



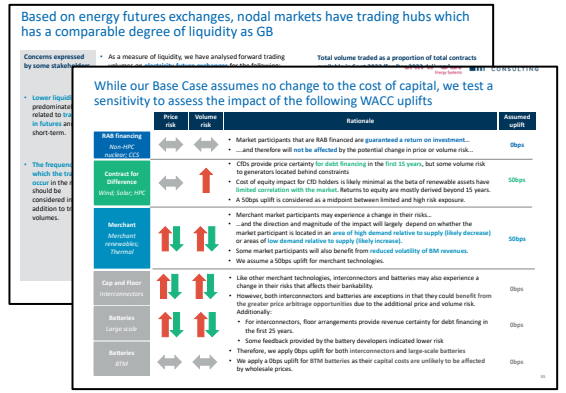
- How some consumers (or their suppliers if delegated the authority) might operate their heat pumps in a smart, flexible manner in response to daily prices

Benefits of Transmission network investments



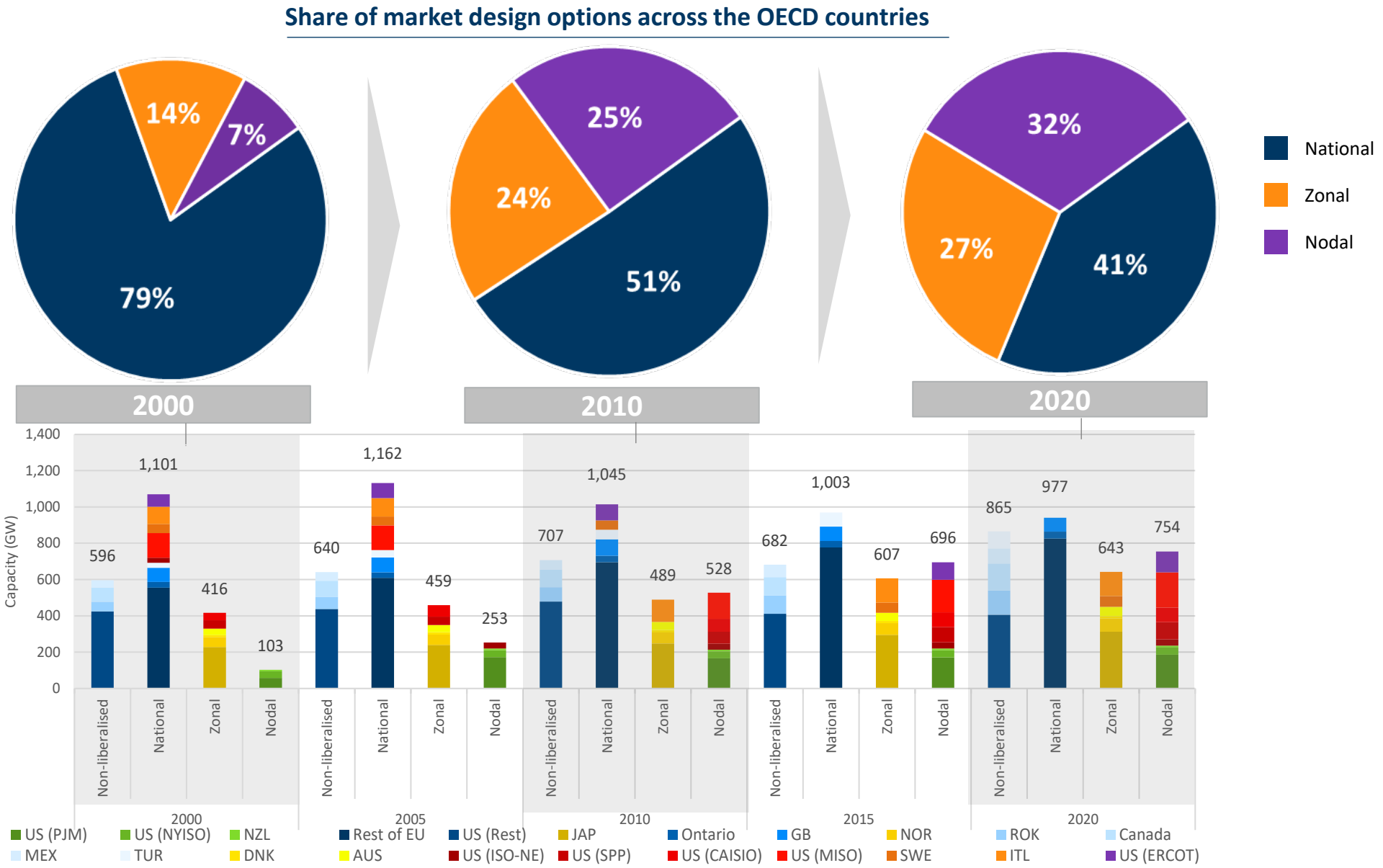
- How the choice of market design could impacts the way in which the benefits of transmission investments are evaluated and assessed

Wider system impact



- Impact of different market design options on financing costs
- Impact on Liquidity
- Consideration of relevant subsidy schemes

Final point: nodal and zonal pricing increasingly common across world's liberalised electricity markets. EU countries and GB are the main national pricing markets



Notes: (1) chart includes OECD member countries (as of 2000) except Iceland. Sources: IRENA, CAISO, NYISO, ERCOT, MBIE NZ, Potomac Economics, IESO, DUKES, FERC, SPP, ISO-NE

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