Nodal pricing in GB: Brief overview of conclusions and impact on use of flexibility resources
Introduction to the FTI Team
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

**Australia & New Zealand**
- **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 – TUsS and Abu Dhabi DUoS charges
- **Final user tariffs** for the KSA Water sector for WERA
- **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.
All experience and capabilities

Market design: Great Britain — Review of electricity market arrangements

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 ZERO¹ 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 SIGNALS³

- 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 REFORM⁴

- 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

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

- 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, PROCUCE AND SCHEDULE ESSENTIAL SYSTEM (ANCILLARY) SERVICES

- 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

- 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

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

In response to these emerging issues and Net Zero ambitions, Ofgem has commissioned FTI to develop a detailed locational GB power market model...
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 across GB (29th Sept 2040 – 12:00)*

2 *Example of a very high wind hour in Scotland and northern England (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.

- 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).

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

<table>
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<th>National</th>
<th>Zonal</th>
<th>Nodal</th>
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<tbody>
<tr>
<td>LtW (NOA7)</td>
<td>£72.60</td>
<td>£47.40 - £79.30</td>
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<tr>
<td>LtW (HND)</td>
<td>£72.60</td>
<td>£47.50 - £79.40</td>
<td>£37.40 - £81.40</td>
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<tr>
<td>SysTr (NOA7)</td>
<td>£75.00</td>
<td>£53.90 - £76.90</td>
<td>£42.90 - £80.10</td>
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### 2030 - Load weighted annual average wholesale prices, £/MWh

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<th>National</th>
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<tr>
<td>LtW (NOA7)</td>
<td>£23.50</td>
<td>£17.40 - £29.20</td>
<td>£13.80 - £31.00</td>
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<tr>
<td>LtW (HND)</td>
<td>£23.50</td>
<td>£21.00 - £24.90</td>
<td>£18.50 - £27.40</td>
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<tr>
<td>SysTr (NOA7)</td>
<td>£25.70</td>
<td>£20.40 - £28.20</td>
<td>£17.20 - £31.00</td>
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### 2035 - Load weighted annual average wholesale prices, £/MWh

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<tr>
<td>LtW (NOA7)</td>
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<tr>
<td>LtW (HND)</td>
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<td>£31.10 - £37.00</td>
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<tr>
<td>SysTr (NOA7)</td>
<td>£29.90</td>
<td>£25.80 - £31.40</td>
<td>£22.80 - £35.00</td>
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### 2040 - Load weighted annual average wholesale prices, £/MWh

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<th>National</th>
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<tr>
<td>LtW (NOA7)</td>
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<tr>
<td>LtW (HND)</td>
<td>£50.90</td>
<td>£43.00 - £48.90</td>
<td>£37.50 - £56.40</td>
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<tr>
<td>SysTr (NOA7)</td>
<td>£30.20</td>
<td>£27.60 - £32.20</td>
<td>£21.20 - £38.40</td>
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The GB constraint costs increased significantly since 2010 and we forecast a trend to continue under the current market design.
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)**

- **Reduced cost of congestion management**: £48.8bn
- **Intra-GB congestion rents, akin to ‘arbitrage revenues’ between nodes**: £27.1bn
- **Accounts for higher wholesale costs faced by GB consumers**: £12.7bn
- **Intra-GB congestion rents, akin to ‘arbitrage revenues’ between nodes**: £11.9bn
- **One-off implementation costs**: £0.5bn
- **Accounts for the lost wholesale & balancing market revenues earned by generators**: £38.2bn
- **Accounts for additional generation revenue from CfDs**: £11.9bn
- **Total GB Socioeconomic Benefits**: £24.5bn

*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**

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

“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

- 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%

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.

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) 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%.

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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.

- 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

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

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

Benefits of Transmission network investments

Wider system impact

- Based on energy futures exchanges, nodal markets have trading hubs which has a comparable degree of liquidity as GB

- While our Base Case assumes no change to the cost of capital, we test a sensitivity to assess the impact of the following WACC uplifts

Impact of different market design schemes on financing costs

- Returns to equity are mostly derived beyond 15 years.
- Lower liquidity

- Nodal markets have trading hubs which has a comparable degree of liquidity as GB

- Additional return is generated from the potential change in price or volume risk...

- Each product has slightly different contract definitions (size, pricing and volumes on related to electric investments capital costs are unlikely to be affected by the potential change in price or volume risk...)

- The comparable products we have assessed are:

- Contract for Difference (CfD) schemes, which provides price certainty at a particular node

- Interconnectors and batteries could experience a reduced volatility of BM revenues

- BTM batteries: guaranteed a return on investment for the following: 0.40 0.60 0.80 1.00 1.20

- The evidence we found is that returns to equity are mostly derived beyond 15 years.

- Some feedback provided by the battery developers indicated lower risk

- Like other merchant technologies, interconnectors and batteries may also experience a lower liquidity

- Nodal Price

- …and the direction and magnitude of the impact will largely depend on whether the change in their risks that affects their bankability.

- The frequency at which the trades were made in a month...

- Heat Pumps

- 03/04/2040 03/05/2040 03/06/2040

- HP Load  Nodal Price

- £/MWh

- 0 20 40 60 80 100 120 140

- 03/04/2040 03/05/2040 03/06/2040

- GB1 GB2 GB3 GB4 GB5 GB6 GB7 GB8

- CAP and Floor

- Difference

- Merchant

- Non Thermal

- Thermal

- BTM

- Nuclear; CCS

- HPC

- Large scale

- Wind; Solar; HPC

- Interconnectors

- Batteries

- RAB financing

- Market participants that are RAB financed are assumed a 50bps uplift for merchant technologies.

- We assume a 50bps uplift for merchant technologies.

- The number of days in that month where a trade was made (RHS)
**Final point:** nodal and zonal pricing increasingly common across world’s liberalised electricity markets. EU countries and GB are the main national pricing markets.

**Share of market design options across the OECD countries**

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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