Interconnector Ramping CBA

Report Presentation

NG - ESO

28 04 2023

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Agenda

Agenda Items		
	Introduction	• Team introductions - Ronan • Project background and Scope - Ronan
	Background	• Review of Project Plan - Ronan • High Level overview of methodologies utilised - Meerav • Options and Shortlisting - Ronan
	Methodologies utilised	• Ramp Management Balancing Costs - Meerav • PLEXOS modelling - Josh • Cost Benefit Analysis (CBA) – Josh/Alex
	Project conclusions	• Results and conclusions – Alex/Ronan • Q&A - All

Project Purpose

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Project Background and Scope

We conducted an independent Cost-Benefit Analysis to assist an upcoming Grid Code modification

Background

- Ofgem has requested the ESO raise a Grid Code modification to include interconnector ramping within GB frameworks to be fully compliant to SOGL Article 119 after EU-Exit
- Current arrangements allow interconnectors to ramp at 100MW/min. The combined swing size and ramp rate of these interconnectors may be causing operational costs and difficulties for the control room to manage efficient consumer cost and system security
- GB has five interconnectors connected between UK and Continental Europe today. With up to 8 continental interconnectors are expected by 2035
- The ESO wish to review interconnector ramping arrangements before submitting their Grid Code modifications to ensuring a safe and secure transmission system whilst delivering consumer value

Scope

Overall scope: conduct a Cost-Benefit Analysis to indicate which option the ESO should opt to include in their Grid Code modification

- Step 1: Confirm our overall methodology and socialise with the ESO and industry stakeholders
- Step 2: Shortlist options using a structured methodology with the ESO and WG
- Step 3: Utilise PLEXOS and other bespoke modelling to determine I/C flows, ramp rates, costs to various defined parties (inc. Ramp Management)
- Step 4: Combine and evaluate costs in our CBA framework, with the following groups considered: interconnectors, consumers, ESO

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Project Plan

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Project Timeline

Our independent CBA engaged stakeholders across the ESO and industry (via Working Group 0154)

Dates	Phase	Actions	Engagement
04/01- 22/01	Develop and finalise CBA methodology	• Worked with the ESO to confirm the core components of each option • Identified publicly available data sources to support our assessment • Determined our data driven approach on how to quantify the costs and benefits of the option	• Internal ESO methodology update (11/01) • ESO data workshop (16/01) • Methodological approach presented at **Working Group 7** (18/01)
23/01- 03/02	Shortlisting	• Developed a list of criteria to shortlist options • Iterated shortlisting criteria with the ESO in a series of workshops • Conducted an internal scoring session to evaluate options using expert judgement and other qualitative evidence to shortlist c.3 options • Held a review and challenge session on our scoring with the ESO • Co-created alternative options based on feedback from ESO and WG (see slide 11)	• ESO shortlisting criteria workshops (19 + 26/01) • Baringa shortlisting session (26/01) • ESO challenge + review session (31/01) • Shortlisting outcomes review held with Working Group and facilitated their feedback and input to final Options **Working Group 8** (09/02)
03/02 – 21/04	Modelling + CBA Analysis	• Agreed key balancing cost modelling assumptions with ESO, including the price scenarios and interconnector connections to use in our PLEXOS model • Conducted analysis detailing the average ramp rate, frequency of high ramp events and impacts on balancing costs on the different options • Conducted PLEXOS modelling on the different options over a set time horizon • Estimated interconnector revenues (with no imbalance costs provided) • Conducted qualitative analysis on implementation and operational costs • Determine CBA results based on monetised and non-monetised costs and benefits	• ESO CBA + ramp mgmt. cost workshop (22/02) • Discussion on alternative options at **Working Group 9** (23/02) • ESO ramp mgmt. balancing cost workshop (21/03) • Presented proposed options to model at **Working Group 10** (22/03) • Working Group feedback incorporated into final option design
21-28/04	Prepare + Present Report	• Finalise the report and present our findings to ESO and the Working Group	• ESO + Ofgem Internal Report (28/04) • **Working Group Session 11** (09/05)

Note: Weekly project management update calls were held with the ESO

Methodology Overview

Methodology Overview

Our CBA used inputs from PLEXOS and bespoke Ramp Management Balancing cost modelling

Refine Options

- From our shortlist, we defined our options in further detail

Pan-European Day Ahead Model

- To model interconnector flows we used our internal PLEXOS Pan-European Day Ahead model at 15 minute granularity
- This model is regularly used by industry and uses a set of base assumptions (see appendix C)
- This was used to determine:
  - ▷ IC flow volumes (MW)
  - ▷ IC Revenues (£)
  - ▷ Social Economic Welfare (£)
  - ▷ Wholesale prices (£/MWh)
  - ▷ Carbon impact (gCO2/MW)

Ramp Management Balancing Costs

- Created a bespoke approach to model balancing costs
- This accounted for Reserve, Repositioning, Response and Frequency Control actions
- We used 2022 data to determine volume of average action per given swing magnitude, noting costs would be distorted by market effects
- We found a strong non-linear correlation (0.98) between I/C swings and volume (MW) of BOAs + ASDP instructions
- We used a line of best fit to extrapolate volume required
- To calculate ramp management balancing costs, we multiplied projected wholesale price * VOL Balancing Services required based on swing projection

Cost Benefit Analysis

- We designed a CBA tool to evaluate costs from PLEXOS and Ramp Management Balancing
- Qualitative non-monetised costs were added from additional analysis

Refine Options

The following options were agreed – noting implementation method is out of scope in this analysis

Option		Description
2C	**Baseline: Keep current ramp rate** (100MW/min)	Use existing ramp rate for continental I/Cs (100MW/min). All other interconnectors use their default rates (e.g., EWIC, Moyle, NSL).
1A	**Ramp Management** (Curtail Ramp Rate based on Swing Size)	Use existing ramp rates for continental I/Cs (100MW/min) with a reduction of ramping rates at anticipated points of system stress. For modelling this is defined by a 3500MW+ total swing. All other interconnectors use their default rates (e.g., EWIC, Moyle, NSL).
2B	**Static Lower Ramp Rate** (50MW/min)	Change continental interconnector base rate ramp limit to match generators (50MW/min). All other interconnectors use their default rates (e.g., EWIC, Moyle, NSL).
3.1	**Dynamic Ramp Rate Periods** (100MW/min <-> 50MW/min)	Ramp rate changes to meet system needs. Base ramp rate set at 50MW/min with increased ramp rates made available when system conditions allow for this (raised to 100MW/min at certain time periods for import or export based on anticipated demand movement). All other I/Cs use their default rates (e.g., EWIC, Moyle, NSL).

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Options and Shortlisting

Options Considered for Shortlisting

We refined options developed by the Working Group which were subsequently presented for shortlisting

Overarching Options

#	Group	Option	Description
1	Ramp Mgmt Tools	a) TSO Ramp Management	Use the existing ramp rates in Interconnector agreements and add to the Grid Code. Use Ramp Management agreements that are in tripartite agreements (not necessarily in all current agreements)
		b) TSO-TSO arrangements	Use the existing ramp rates in Interconnector agreements and add to the Grid Code. Utilise European balancing platforms to allow for optimisation of products in the market when simultaneous fast ramping requires counteraction. ***Additional trading would be informed by day-ahead reference programmes.***
2	Ramping arrangements	a) Dynamic ramp rate	Base ramp rate of 50MW allocated to all Interconnectors. Additional ramping to be made available based on day ahead forecasting of up to 250MW with a max ramp rate of 100MW. The additional ramping is based on the rate of change of demand forecast.
		b) Static ramp rate	Change interconnector base rate ramp limit to match generators (50MW/min). ***Evaluate and then further compare effect of alternative rates.***
		c) Static ramp rate (status quo)	Interconnectors currently connected to the system have a ramping maximum of 100MW - continue with this rate. ***This represents our proposed baseline.***
3	Market Based Solutions	a) Procure increased Frequency response	ESO to hold sufficient Frequency Response to facilitate up to 100MW/min interconnector ramping. ***This will take into account FRCR policy.***
		b) Base rate set for all IC and a market would be created for IC to participate	Each IC gets a 'banked' 50 MW, and the extra 50 MW is multiplied across the number of ICs, then a market is run for this availability. The IC to choose if they wanted to be in that market. ***As this is a variant of 2a+2b, this option will require further analysis.***
		c) Create a ramping market	ESO to set up a "ramping market" where, based on the day ahead position of trade and risks estimated across ramping transition a volume dependent escalating ramping price is identified reflecting the costs incurred in operating the GB system, which allows the benefits of offsetting that position to be reflected by those offering flexibility to mitigate it whether interconnectors or other providers

Our Shortlisting Process

We conducted a structured process to shortlist 3 options to review against the base case

Criteria	Sub criteria
Adaptability	Ease of codifying in the Grid Code
Commercial impacts	Change required to external arrangements (i.e. external tripartite agreements)
	Interconnector revenue impact should be calculable
	ESO Balancing costs should be calculable from analysis
Compatibility with other users	Similarity to other grid code arrangements (e.g. generators)
Decarbonisation	Decarbonisation impact is calculable
Energy Security and system operability	Decrease likelihood of frequency events
GB/Europe Consumer Benefit	Modelling can demonstrate consumer benefit or cost
Implementation	Ease of implementation
	Implementation cost
	Speed of implementation
Interoperability with Europe	Technically viable with European GCs and technological constraints
	Non-discriminatory to current or future interconnectors
	Minimise operational costs on (other) both TSOs.
Modelling Viability	Data availability
	Publicly available data
	Modelling duration
	Modelling accuracy

- An initial long list of shortlisting criteria was presented to the WG, this was then iterated and further refined based on feedback provided (see right for final criteria)
- Baringa conducted an internal scoring session followed by a challenge and review session with the ESO
- The outcome of both these sessions was presented back to the WG
- During this session we indicated our provisional recommendations for options that should be modelled further in detail:
  - Option 2C – keeping ramp rates at 100MW/min as the base case for other options to be compared against as this is the status quo
  - Two other options for detailed analysis emerged from the scoring undertaken i.e., Option 2B and Option 3A
- Following feedback from the Working Group, additional time was taken to enable the WG to select its preferred options. The WG preference was for Option 1A and 3A.
- Following additional refinement and reflection of Option 3 (on further analysis Option 3A was deemed out of scope) elements of 3A/B/C were combined to create Option 3.1
- Therefore, Option 1A, 2B, 2C (becomes base case), and 3.1 were taken into the analysis stage

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Balancing Costs for IC Ramp Management

Ramp management actions

We mapped various ESO actions to manage interconnector ramping and their associated impacts

Interconnectors

ESO Actions

Impacts

IC ramp

Normal actions →

Typical ESO actions to manage anticipated ramping within the system

Re-positioning BOAs
- Ramps against ramp
- Cover energy imbalance

→ Potentially set Settlement Period £/MWH

Additional regulating reserve
- Uncertainty
- Additional Response

→ Additional balancing costs | System security cost

Additional voltage support
- Requirement during certain system conditions (typically in SE England)

→ Additional balancing costs

Additional actions →

Only required if normal actions are insufficient

Frequency control actions
- Short duration
- Potentially high cost

→ Additional balancing costs | System security cost

Balancing Costs Methodology

We used various public datasets to assess the relationship between I/C Ramping and Balancing actions

Calculate the volume of Balancing actions required for Ramp Management in 2022 using public data and operational insights

↓

Assess whether a relationship exists between volume required and I/C average ramp rate

↓ A statistically significant correlation was found

Apply this relationship to our DA I/C modelled flows 2023-2030

↓

Input estimated Balancing Costs into CBA

- To assess affect of ramping on Balancing actions we explored the existing relationship between high ramp rates and volume of Balancing actions required to manage the ramp
- Using public data, we developed an approach to calculate the volume of Repositioning, Response, Frequency Control and other short term energy actions needed for a given average cumulative ramp rate
- We found a statistically significant relationship exists based on reviewing actions +/- 15 mins to each hour compared to actions taken outside that time
- We further developed a methodology to calculate long-term reserve (where actions needed to be taken between 15-45 mins before an I/C swing) using operational experience
- Our methodology is described in further detail in Appendix A
- *Note: We have used datasets which can be publicly sourced in our analysis (e.g., ESO Data Portal, ElecLink, RNP)*

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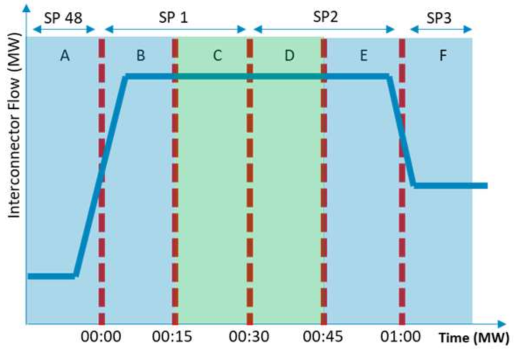
Two analytical concepts used

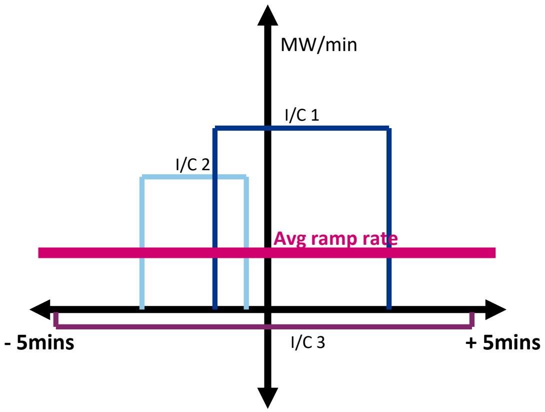
Highlighting two key methodological concepts used to calculate Ramp Management Balancing Costs

Sub-settlement periods



- To determine affect of I/C swings on Response, Frequency Control and other short-term actions we divided each hour into four sub-settlement periods
- 15-minute granularity has been chosen to capture difference between GREEN periods where we expect little cost affect of I/C swings and BLUE periods where we expect costs to be affected by swings

Average Total Ramp Rate



- Interconnectors over 2022 ramp at different times
  - e.g. IFA2 and ElecLink ramped evenly over +/- 10 mins compared to NEMO and Britned that ramped at 100 MW/min for a certain duration. All can spill if ramping over 1000MW across 10 mins
- We need to determine the total average ramp rate to assess how costs across sub-settlement periods differed based on ramp rate
- Using contractual principles and operational experience we calculated an average ramp rate that would be experienced over 10 mins (+/- 5 mins to each hour)
- This method incorporates swing size and duration – as such we believe it is the best estimate we can use however it may dampen the affect I/Cs could have on Balancing Costs

Our Methodology

We used both historical data and operational experience to determine Balancing actions required

Inputs	Analysis				Outputs
BOA Data (Categorised based on instruction time across 96 sub-SPs)	Repositioning	Filter BOAs for repositioning bids (excluding “Response”, “System”, “Constrained Loss”)	Calculate repositioning cost for each action	Determine average cost for each sub-settlement period	Average volume of balancing services per sub-settlement period in 2022 based on swing intervals of 400MW
	Response	Filter BOAs for “Response” bids. Exclude any actions <5 mins	Calculate response cost for each action	Determine average cost for each sub-settlement period	+
	Freq Control	**Filter BOAs for <5 mins duration**	Calculate cost for each action	Determine average cost for each sub-settlement period	Average volume of balancing services per average ramp rate experienced in 2022
ASDP Data (Categorised based on instruction time across 96 sub-SPs)	Freq Control	Filter ASDP for “Fast Response” and “STOR”	Calculate cost for each action	Determine average cost for each sub-settlement period	
Operational expertise	Reserve	Establish with operation teams how much reserve would be required for a given swing size and ramp rate. Note the duration of time reserve is required varies on swing size	Design equation to calculate this Reserve required.		Average cost of reserve per given I/C swing

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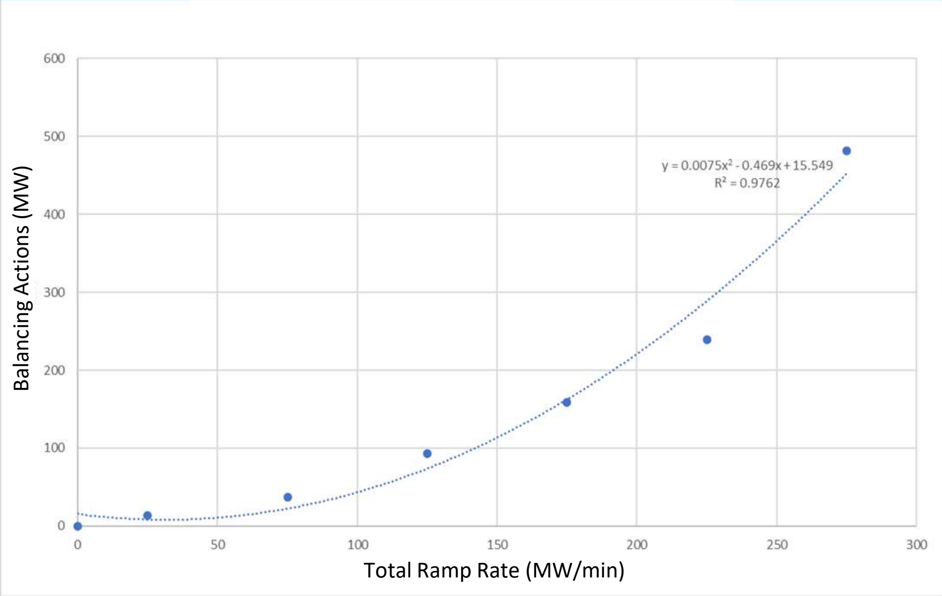
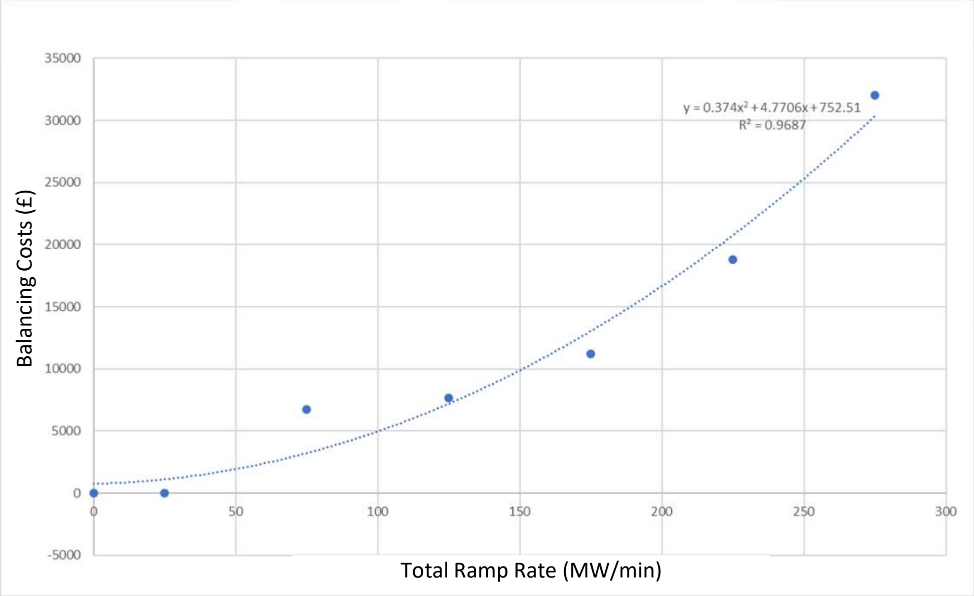
Relationships existed for Repositioning, Response and Frequency Control Actions

Balancing service procurement costs and volumes were correlated to the average total ramp rate

Volume



Cost



**Note only 13 swings occurred over 300-450MW/min. As such these results have been removed from analysis to ensure data reliability*

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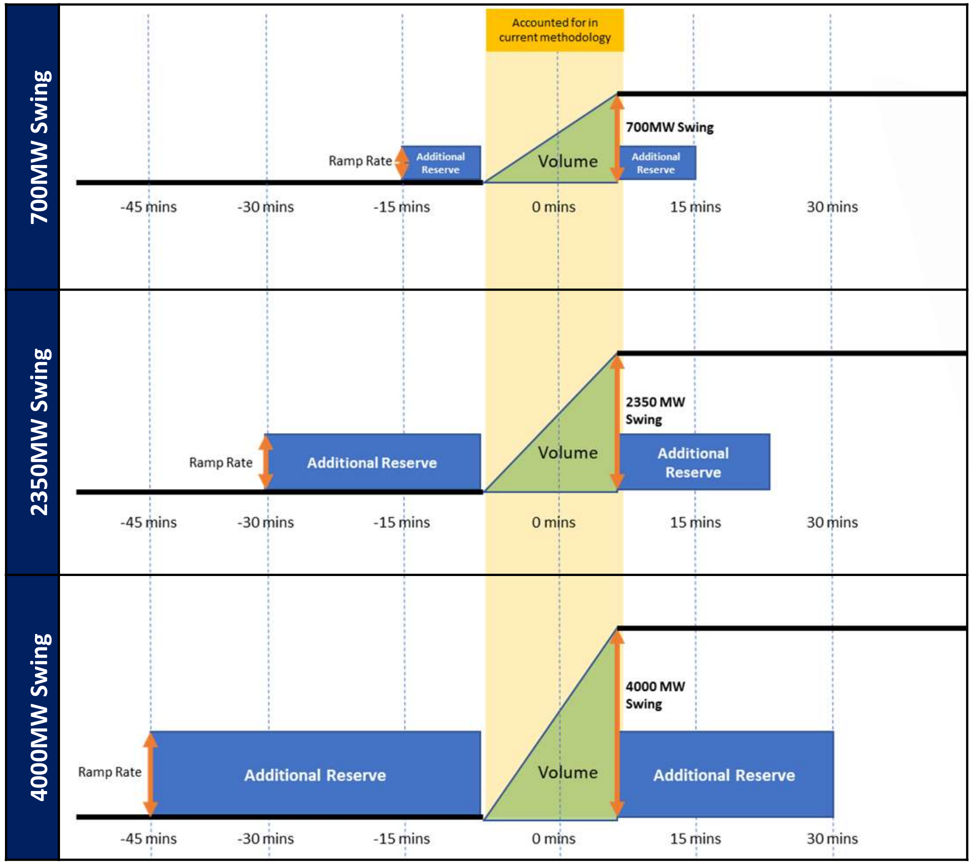
Reserve Calculation

Operational experience helped informed the way we calculated Reserve requirements



- Due to the complexity of ramp management, it is not always possible to untangle the reserve requirement due to interconnectors from other activities
- Therefore, we have reviewed the theoretical basis for requiring reserve to cover uncertainties (inc. energy imbalance)
- For any 700MW swing across continental I/Cs, this additional reserve would be procured within +/- 15 mins of a swing and last less than 30 mins. As such it would be captured by our existing methodology
- However, for overall swing sizes between 700MW – 4000MW additional reserve would be required
- All swings above 4000MW would follow the same calculation as 4000 MW
- This would match the total I/C ramp rate, as this would be the anticipated reserve volume requirement

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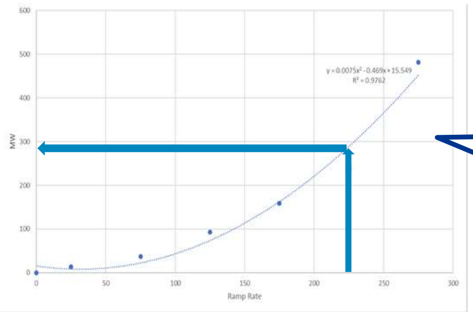
Balancing Cost Analysis

Applying our methodology to an example interconnector swing

Example swing

Time	IFA	NEMO	BritNED	IFA2	Eleclink	Total
00:00	-1000	-500	700	1200	0	400
01:00	2000	500	0	1500	650	4500
Swing	+3000	+1000	-700	+300	+650	4100
Avg Ramp Rate (+/- 5 ms)	100 MW/min	100 MW/min	-70MW/min	30 MW/min	65MW/min	225 MW /min

Repositioning, Response, Frequency Control + Short-term energy actions

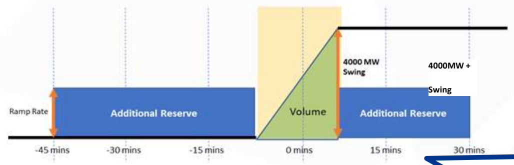


Balancing action volume calculated from relationship seen in 2022 between average total ramp rate and balancing actions taken.

Total volume

289 MW

Reserve



- Swing <700MW: Additional reserve would be procured within +/- 15 mins and be captured in "other energy actions" on left
- Swing 700 – 4000 MW: additional plant needs to be procured at a longer timescale. Linear relationship between procuring 15 mins before and after to 25 mins before and 30 mins after
- Swing 4000 MW+: Control room seek to procure reserve for max time

Total volume

Balancing Actions = Time * Ramp Rate = 1.25hrs * 225 MW/mins = 281 MW

Overall Balancing Volume Required = 569 MW |Wholesale Price £200/MW | Overall Cost £113,800

See detailed methodology in appendix

Balancing Actions Baseline Results

Our analysis shows that the average cumulative ramp rate increases from 2023 to 2030

		2023	2030
Ramp Rate (MW/mins)	0	1806	2585
	0 – 50	2332	1785
	50 – 100	1688	1339
	100 – 150	1087	754
	150 – 200	713	634
	200 – 250	421	432
	250 – 300	278	409
	300 – 350	151	233
	350 – 400	146	216
	400 – 450	49	134
	450 – 500	89	88
Summary Stats	Avg Ramp Rate	89	104
	Avg Price (£/MW)	£221	£60
	Overall Cost (£)	£388m	£168m

We find that the spread of interconnector ramp rates increases in 2030:

- *ICs more 50% more likely to have higher ramp rates above 250MW/mins*
- *Yet simultaneously the overall probability ICs do not swing increases by 9%*
- *Smaller ramp rate probability decreases*

Whilst the average cumulative ramp rates increases, the overall Balancing costs fall due to the wholesale price of energy

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Applying ESO Ramp Management Costs to Modelled Flows

1

Calculate the Total Ramp Rate and Swing Size for each hour (2023-2030)

- Using PLEXOS modelled I/C hourly positions we determine the total swing size of continental I/Cs and the total ramp rate (using same methodology outlined in "Our Methodology" slide)

2

Determine volume of Balancing actions required

- **Response, Frequency Control and Repositioning Reserve**: we use a cost lookup table based on total ramp rate intervals of 50MW
- **Reserve**: apply our formula to determine the length of time Balancing actions need to be procured

3

Apply Wholesale GB Price to calculated volume

- We apply modelled PLEXOS wholesale GB prices to Balancing actions volumes
- These are the best estimated prices that are likely to be experienced
- We acknowledge this may not fully reflect the premium paid to procure energy closer to real-time (based on experience this could be up to 10%)

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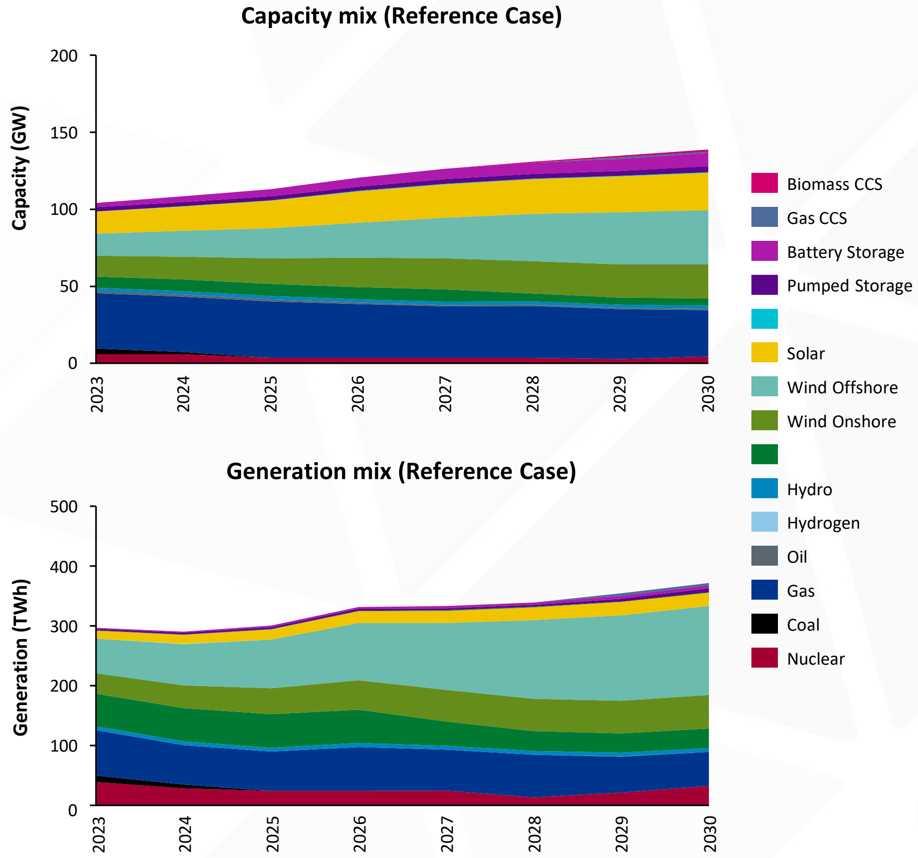
PLEXOS Modelling of Options

Capacity and generation mix – Reference Case

Our modelling scenario is underpinned by our assumptions on new generation capacity build and retirement

- The charts opposite show annual capacity and generation mix in GB in the Reference Case.
- Investment and closure decisions drive changes in the capacity mix and in our modelling are based on a combination of national policy ambition or decisions, and the economics of individual units and generators in the market (i.e. a generator will close where it can no longer cover its costs from market revenues).
- In GB, wind and solar capacity increases significantly due to CfD support for offshore wind in the near term. We project wind capacity (onshore and offshore) to more than double from 27 GW in 2023 to 57 GW in 2030. Solar capacity also increases significantly, from 14 GW in 2023 to 24 GW in 2030.
- Coal-fired generation is phased out by the end of 2024 despite some short-term delay to closures. There are also significant closures of existing gas capacity leading to a downward trend in the contribution of gas to both the capacity mix and generation. This, combined with increasing peak demand, is projected to lead to lower capacity margins.
- A range of technologies are built in the Reference Case, including gas CCS, gas engines and batteries, to meet the target capacity margin of approximately 3% to 5% in the medium to long term. Some existing biomass capacity is converted with the addition of CCS in the late 2020s and nuclear capacity also increases from the late 2020s.
- By 2030, 75% of generation comes from wind, solar, biomass, biowaste and hydro.



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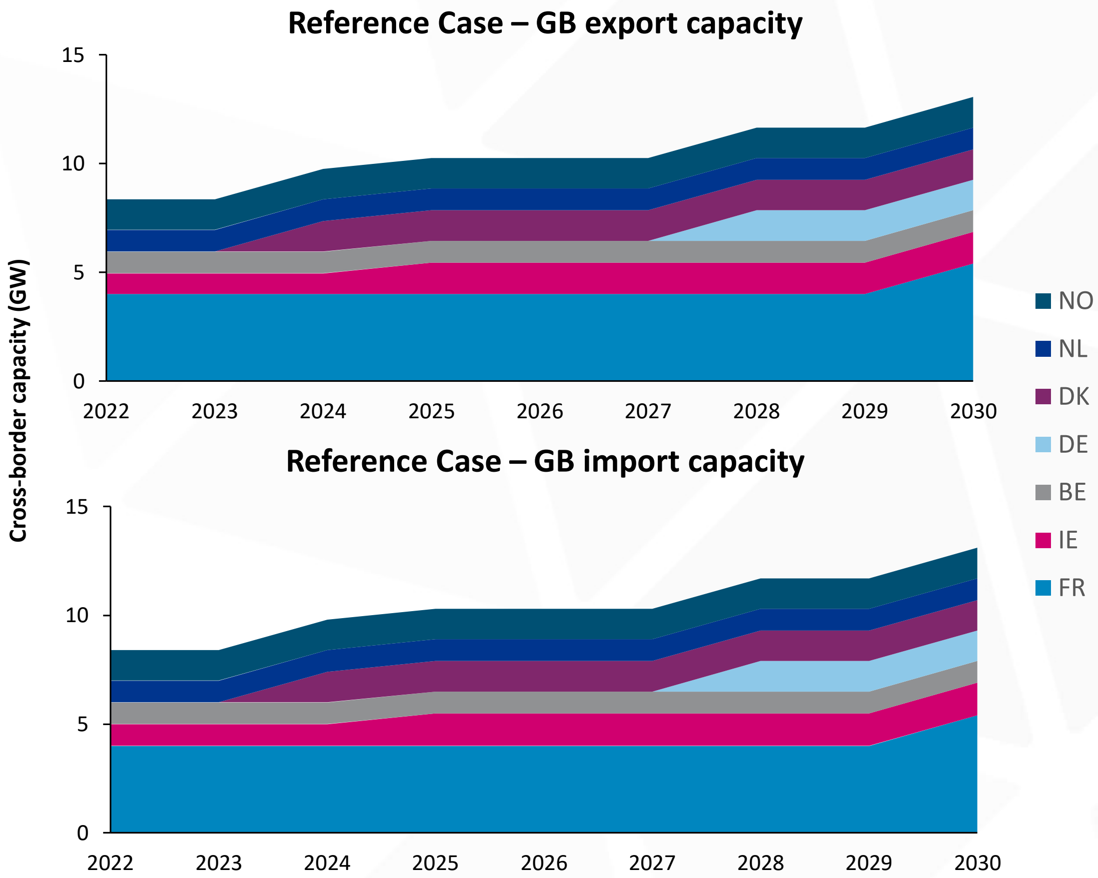
Interconnector capacity – Reference Case

GB interconnection capacity is assumed to increase from 8.4 GW in 2023 to 13.1 GW by 2030

- In the short-term, new capacity build in the Baringa model is based on information on project status and progress, and profitability of each project over the assumed lifetime (in the long-term we rely on economic assessment alone). Our view is developed based on iteration of capacity build on each border. Where price differentials, and the resulting revenue for a new interconnector are sufficiently large to incentivise investment, we take this as a market signal for new investment.
- Great Britain currently has an import and export capacity of 8.4 GW.
- The capacity of interconnection is expected to increase in the future as existing projects in the pipeline come online supported by positive economics due to the hourly price differentials between markets.
- Export and import capacity is assumed to increase to 13.1 GW by 2030 in the Reference Case. This is due to additional interconnection capacity with France and adding new interconnection capacity with Denmark and Germany. The NeuConnect interconnector with Germany is now projected to become operational by 2028.
- We note that there are a number of additional projects that may come forward in Ofgem's Cap and Floor window 3 which have not been modelled explicitly in this study. Our approach to date has been to consider medium-term projects based on project economics rather than picking winners from the range of projects currently in the pipeline.



Our reference case

We use the yearly base assumptions below

Baringa Reference Case
2022 Q4
Great Britain
Data is in real 1st Jan 2022 money unless stated otherwise

Prices - Fuels and Carbon		2023	2024	2025	2026	2027	2028	2029	2030
Crude Oil Brent	*$/bbl*	78.4	70.3	65.7	62.4	65.2	71.3	77.5	81.3
Coal CIF ARA	*$/tonne*	182.1	165.5	150.2	139.9	127.4	106.6	85.9	72.9
Gas NBP	*p/therm*	262.1	212.5	148.4	84.4	80.4	73.1	65.8	61.9
Carbon UKA+CPS	*£/tonne*	74.1	83.2	86.1	82.6	78.3	75.8	74.9	73.2
Carbon UKA**	*£/tonne*	58.1	67.8	71.2	69.1	67.7	68.1	70.1	71.4
Carbon CPS	*£/tonne*	16.0	15.3	14.9	13.6	10.6	7.7	4.8	1.8

Demand		2023	2024	2025	2026	2027	2028	2029	2030
Peak Demand	*MW*	59,266	60,265	61,148	62,037	63,051	64,143	65,018	65,882
Annual Demand	*GWh*	310,755	316,314	322,039	327,568	333,075	338,710	347,550	356,707

Installed Capacity by type		2023	2024	2025	2026	2027	2028	2029	2030
Nuclear	*MW*	5,873	5,873	3,538	3,538	3,538	3,538	2,798	4,398
Coal	*MW*	3,764	1,500	0	0	0	0	0	0
Gas	*MW*	35,927	35,803	36,628	34,915	33,532	33,632	32,327	30,087
Gas CCS	*MW*	0	0	0	0	0	0	900	900
Oil	*MW*	1,472	1,506	1,480	1,104	878	878	878	878
Hydrogen	*MW*	0	0	0	0	0	0	0	0
Hydro	*MW*	2,017	2,027	2,037	2,047	2,057	2,067	2,077	2,087
Biomass and Waste	*MW*	7,263	7,689	7,789	7,889	7,989	5,200	4,655	4,755
Biomass CCS	*MW*	0	0	0	0	0	600	1,200	1,200
Wind Onshore	*MW*	13,519	14,794	16,730	19,042	20,242	20,917	21,442	21,967
Wind Offshore	*MW*	14,302	16,781	19,477	22,737	26,405	30,895	33,851	35,251
Solar	*MW*	14,242	15,842	17,792	20,392	21,592	22,367	23,266	24,165
Other Renewables	*MW*	125	170	215	260	305	350	395	440
Pumped Storage	*MW*	2,828	2,828	2,828	2,828	3,128	3,128	3,128	3,828
Battery Storage	*MW*	2,839	3,719	4,597	5,829	6,584	7,334	8,004	8,804

Interconnection Capacity		2023	2024	2025	2026	2027	2028	2029	2030
Import Capacity, Total	*MW*	8,400	9,800	10,300	10,300	10,300	11,700	11,700	13,100
Export Capacity, Total	*MW*	8,350	9,750	10,250	10,250	10,250	11,650	11,650	13,050

New interconnectors between 2023 – 2030 (study horizon)

We make the following assumptions on new interconnector additions to GB

Interconnector	Capacity (MW)	Connection Date in Model
Denmark	1400	2024
Ireland	500	2025
Germany	1400	2028
France	1400	2030

Please note this is based on our experience and does not reflect that we believe others will not be build and connected

Modelling Outputs | Price results

New ramp rate options have very little impact on annual average wholesale prices across Europe

Static Ramp Rate Option (2C) – status quo

Country	2023	2024	2025	2026	2027	2028	2029	2030
BE	213.71	165.45	130.02	95.08	90.60	81.53	73.33	67.33
DE	187.86	157.54	126.47	94.74	90.58	82.67	74.60	67.90
DK W	179.30	154.88	124.15	90.71	86.98	79.37	70.58	63.97
FR	213.87	162.66	127.77	92.29	86.37	77.98	69.76	64.95
GB	221.26	174.25	134.31	91.69	87.25	78.59	66.62	59.94
NL	200.09	159.57	126.47	93.99	89.89	81.96	73.45	67.25

Static Ramp Rate Option (2B) vs status quo

Country	2023	2024	2025	2026	2027	2028	2029	2030
BE	0.00	-0.01	0.02	0.01	0.01	0.03	0.02	-0.01
DE	-0.01	0.00	0.02	0.01	0.00	0.03	0.02	-0.01
DK W	-0.01	0.00	0.02	0.02	0.01	0.03	0.02	-0.01
FR	0.00	-0.02	0.00	0.01	0.00	0.02	0.01	-0.01
GB	-0.04	-0.05	-0.04	-0.02	-0.02	0.00	0.02	-0.01
NL	-0.01	0.00	0.02	0.01	0.01	0.03	0.02	-0.01

Dynamic Ramp Rate Option (3.1) vs status quo

Country	2023	2024	2025	2026	2027	2028	2029	2030
BE	0.00	-0.01	0.01	0.01	0.02	0.02	0.01	0.00
DE	0.00	0.02	0.05	0.00	0.07	0.02	0.01	0.00
DK W	-0.09	0.04	0.05	0.00	0.06	0.03	0.01	-0.01
FR	0.03	-0.01	0.00	-0.01	0.01	0.01	0.01	-0.02
GB	0.03	-0.01	0.00	-0.04	-0.01	0.02	-0.01	-0.05
NL	0.05	0.01	0.04	0.00	0.02	0.02	0.01	-0.01

TSO Ramp Management Option (1A) vs status quo

Country	2023	2024*	2025	2026	2027	2028	2029	2030
BE	-0.02		0.03	0.01	0.01	-0.04	0.01	0.01
DE	-0.01		-0.01	0.00	-0.03	-0.03	0.01	0.00
DK W	0.02		0.00	0.02	-0.02	-0.06	0.02	0.01
FR	0.00		-0.01	0.02	0.01	-0.07	0.03	0.00
GB	-0.13		-0.23	-0.14	-0.05	-0.44	0.01	0.03
NL	-0.03		0.00	0.00	0.01	-0.03	0.02	0.01

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Cost Benefit Analysis (CBA)

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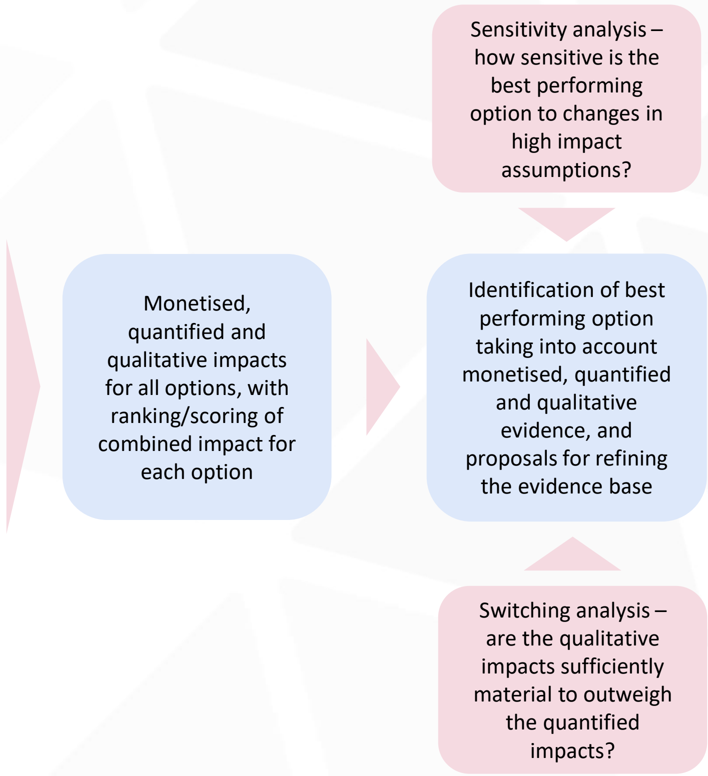
CBA Framework

Our CBA framework combines various tools and datasets to capture a wide range of impacts on the ESO, GB and EU consumers, interconnectors and generators

Costs and benefits included in the CBA

Cost or benefit	Approach	Source
Consumer impacts	Difference in wholesale spot market prices in a given market under the baseline (e.g. 100 MW/min) and alternative option multiplied by total demand	PLEXOS modelling for consumer welfare, qualitative analysis for impact of options on interconnector investment
Producer impacts	Difference in wholesale spot market prices in a given market under the baseline (e.g. 100 MW/min) and alternative option, minus generation costs and multiplied by total generation	PLEXOS modelling for producer welfare
Interconnector impacts	Difference in net revenues realised by interconnectors, taking into account direct changes in revenue from ramp constraints and indirect changes from changes in market participant views of the value of interconnector capacity	PLEXOS modelling for interconnector welfare, qualitative analysis for impact on capacity value
Balancing costs	Additional costs incurred by the ESO associated with repositioning, frequency control actions and other response actions	Analysis of ESO costs
Implementation costs	Additional costs to the ESO and industry from the set up and ongoing costs of the alternative options relative to the baseline	Estimated implementation costs from ESO and interconnectors
Other quantified impacts	Broader impacts, for example from changes in emissions ($MtCO_2/yr$) measured at the social cost of carbon	PLEXOS modelling plus HMG Green Book carbon values
Other non-quantified impacts	A range of potential costs and benefits, including impacts on security of supply and on connecting TSO market etc.	Qualitative review and analysis



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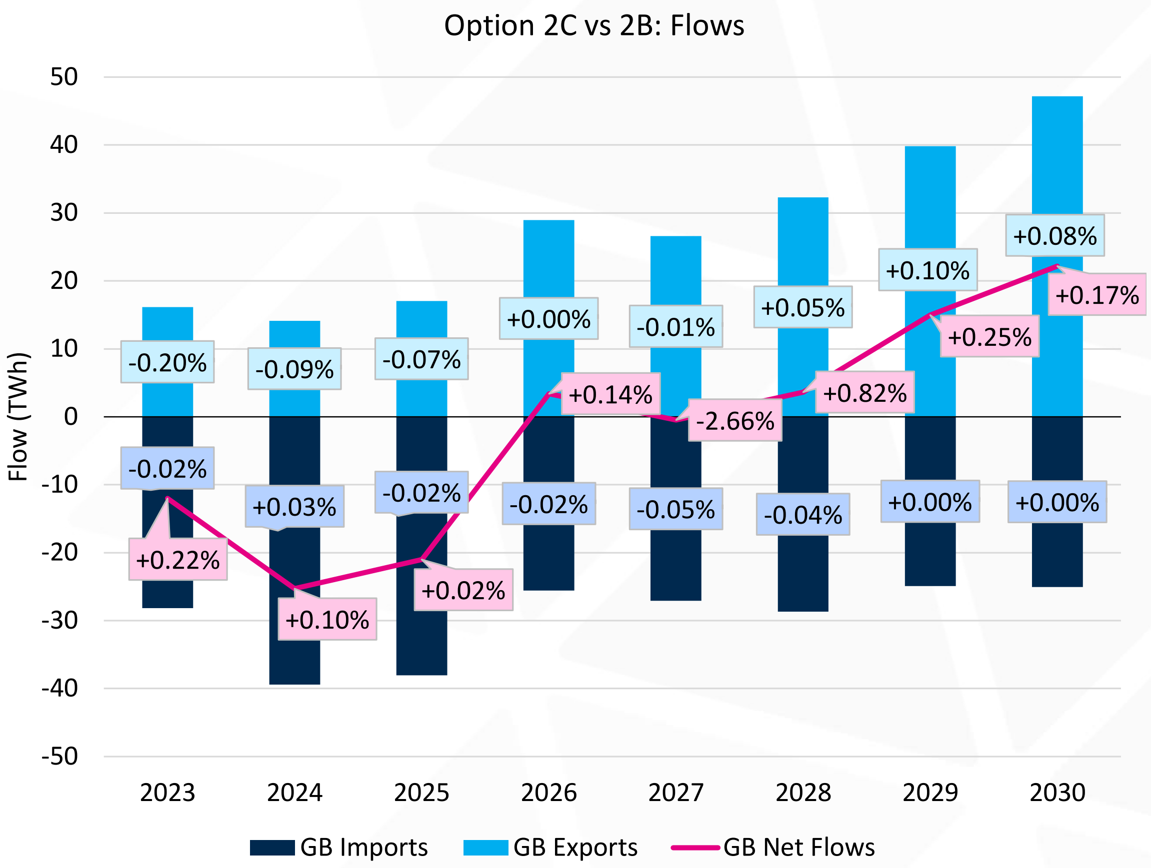
Modelling Outputs | Flow impacts

Changes in interconnector flows as a result of new ramping options are small

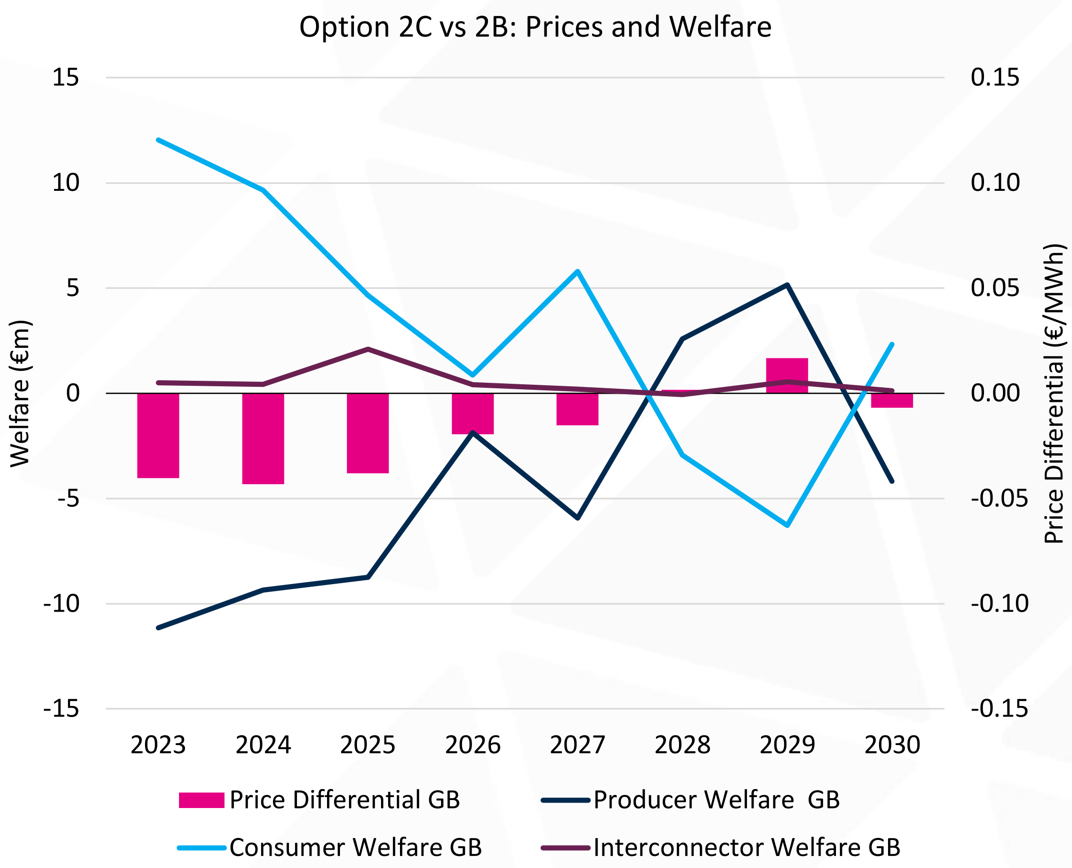
- In the chart on the right imports are denoted as negative and exports are denoted as positive. Negative net flows indicate GB is net importer whilst positive net flows indicate GB is a net exporter.
- The data labels show the differences between the 50MW/min option (2C) and the base 100MW/min option (2B). There are very small changes in flows between modelled options.
- GB is a net importer in the first half of the modelled timeframe then switches to net exporter.
- The modelling shows that the total flow volume increases with time across all ramping options. This is due to the increased price volatility induced by growth in renewable capacity over time.
- We see that in the majority of years, the average impact of the new ramping rate enhances the net flow position i.e. GB becomes a stronger net importer in net importing years, and a stronger net exporter in net exporting years.
- As shown previously, interconnectors can ramp both early and late in response to new ramp rate. As these behaviours are complex, the ultimate impact on import and export volumes is not a simple relationship.
- Interconnector revenues can both gain and lose as a result of the new ramping characteristics. On an annual basis, sometimes gains cancel losses (and vice versa).
- Interconnector revenues are driven by price differentials and flow volumes. As we see marginal changes across both metrics between the modelled options, the resulting impact on interconnector welfare in the CBA is very low.



Modelling Outputs | Price impacts

Wholesale electricity price differentials are the key driver in producer and consumer welfare impacts

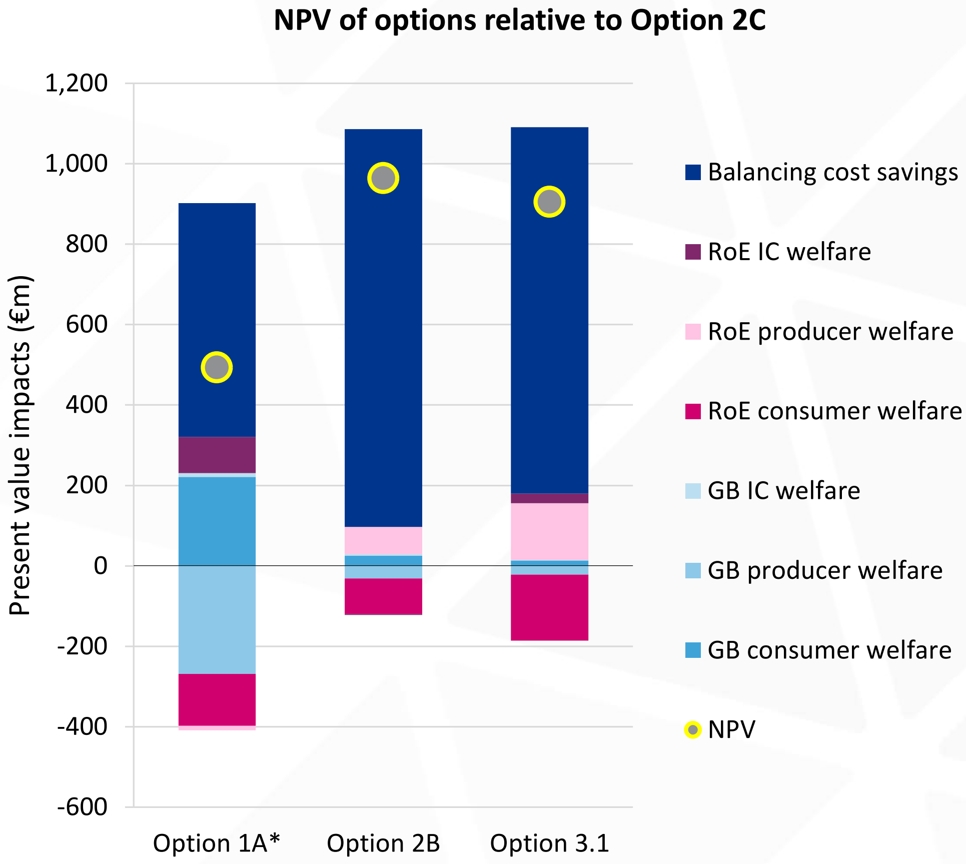
- Compared to the baseline 100MW/min ramp rate, reducing the ramping rate to 50MW/min results in lower prices in GB in the majority of years across the modelled time frame.
- It is important to recognise that the change in wholesale price is very small. Therefore on a relative basis, this has a low impact on overall welfare costs and benefits for producers and consumers.
- When comparing the modelled options, if prices fall then consumers will benefit, however if prices rise then producers will benefit.
- We can see in the modelling that prices in GB are lower in the first half of the modelled horizon, which means GB consumers gain. GB producers lose out as they are not able to earn as much per MWh of electricity sold.
- In years 2028 and 2029, this dynamic changes temporarily, whereby GB experiences an increase in prices with the lower ramp rate. This benefits producers whilst consumers lose out.
- In the early years, GB is a net importer. Reducing the ramp rate results in a larger volume of lower cost imports from surrounding markets due to the additional time taken to ramp up/down. This causes the GB wholesale price to fall.
- Later in the horizon, GB becomes a net exporter and we see the same behaviour but in the opposite direction, therefore raising the GB wholesale price and switching the benefits from consumer to producer.



CBA Outputs | Monetised impacts

All options analysed would deliver an overall net benefit to society over an 8-year horizon

- Reducing the ramp rate provides and overall net benefit relative to maintaining the current 100 MW/min ramp rate. Moving to a 50 MW/min ramp rate (2B) results in a net benefit of €964m , introducing a dynamic ramp rate (3.1) results in a net benefit of €905m and moving to a ramp management option (1A) results in a net benefit of €494m*.
- The main driver of the overall results is the balancing cost savings in both options. The net welfare impacts are close to zero when balancing costs are excluded from the monetised impacts.
- In GB, consumer welfare increases over the modelling horizon as a result of the small reduction in GB prices under the 50 MW/min and ramp management options relative to the 100 MW/min option. Producer welfare moves in the opposite direction as the reduction in prices negatively affects generator revenues. The impacts are however marginal, with producer welfare impacts for example being equivalent to around 0.01-0.03% of overall producer welfare.
- Interconnector welfare appears to increase slightly over the modelling horizon as the divergence in prices caused by a lower ramp rate outweigh any reduction in flows seen in some years.
- This analysis only captures the costs and benefits that it has been possible to monetise through the PLEXOS modelling and balancing cost analysis. Other qualitative impacts need to be considered to get a complete picture on the CBA. In the following slides we show the overall impacts as a RAG assessment to combine both monetized, quantified and qualitative impacts.



*Results for option 1A to be finalised

CBA Outputs
Qualitative impact assessment

Key:	<£5m	£5-10m	>£10m	Minimal impact

Qualitative	Description	Option 1A	Option 2B	Option 3.1
Security of Supply	A varied and technically diverse range of energy sources are required to ensure a high level of security of supply for the UK. The utilisation and growth of interconnectors are important part of the UK policy in this space, therefore any potential option proposed must ensure that this is not put this growth at risk. This growth needs to be balanced against its impact on the operability and security of the system from multiple Interconnectors ramping in the same operational envelope. This should also include any potential increase in the number of actions required to be taken by the System Operator to mange these ramps.	[Minimal impact] Small reduction on Operability Risks due to ability to request reduced ramp rate	[Minimal impact] Large reduction in Operability Risks by reducing the combined ramp rate	[Minimal impact] Reduction in Operability Risks due to SO ability to define periods of increased ramp rate
Implementation Cost	All options should be considered against any requirements that change the current process, system, therefore this cost of implementation need to be considered as part of the overall costs	[£5-10m] Minor IT system changes to all parties	[<£5m] No change to current IT systems	[>£10m] Major IT systems changes to all parties
Impact on Interconnector investment	The ability to create a robust business case for investment in the growth of interconnector needs to be considered as part of this CBA. The chosen options need to consider the impact on the revenue that an Interconnector can make when analyzing the different options. If there is a significant fall in revenue then this may impact on any business case to invest in new interconnectors, this need to be balanced by ensuring that interconnectors do not make excessive profits at the expense of the end consumer.	[£5-10m] Largest positive impact on GB IC revenues	[<£5m] Positive impact on GB IC revenues	[<£5m] Very slight positive impact on GB IC revenues

Note: Key for "Security of Supply and "Impact on Interconnector investment" are based on CBA results

"Implementation Costs" will benefit from additional analysis in the future based on further details on any implementation approach adopted

CBA Outputs | Sensitivities

To allow for potential modelling and data inaccuracies

Due to the number of variables within any modelling technique when simulating over a long time horizon and allowing potential data inaccuracies it is normal to test the results over a range, for the purpose of this analysis a range of 80% to 120% was chosen. The range of results can be seen below. Even when allowing for this wide range

- Balancing costs remain the main driver of the overall NPV
- Small changes in assumptions on balancing costs could lead to material impacts
- A reasonable low scenario would be 20% reduction, and there would still be a large net-benefit from reducing the ramp rate e.g., Option 2B

	Option 2C 100MW €m	Option 1A Ramp Management €m	Option 2B 50MW €m	Option 3.1 Dynamic Ramping Periods €m		1A vs. 2C (saving) €m	2B vs. 2C (saving) €m	3.1 vs. 2C (saving) €m
	1, 671 – 2,507	1,032 – 1,548	768 – 1,151	842 – 1,264		640 – 959	904 – 1,356	829 – 1,243

Note – see Appendix D for full Balancing Cost results

Results and conclusions

Note: Slide has been updated

CBA Results

The qualitative costs and benefits are unlikely to be sufficiently large enough to outweigh the balancing cost savings from reducing the ramp rate or dynamic ramp rate periods

Cost or benefit	1A	2B	3.1	Comment
GB consumer, producer and IC welfare	-€37m*	-€2m	-€6m	GB consumer welfare increases under both 2B and 3.1 as a result of GB power prices falling slightly. The reduction in prices leads to a small reduction in producer welfare in both options. Interconnector welfare increases marginally as the reduction in interconnector flows is outweighed by changes in price differentials between GB and connected markets.
GB balancing cost savings	+€582m*	+€989m	+€911m	GB balancing costs fall significantly under both 2B and 3.1, and are the main driver of the positive net-benefit overall.
Rest of Europe consumer, producer and IC welfare	-€51m*	-€24m	€1m	Changing the ramp rate via the Options considered have a very small negative effect on EU consumer, producers and IC. Option 2B has a slightly worse effect than Option 3.1.
Implementation costs	Major IT changes required*	Negligible	Major IT changes required	There could be additional costs to the ESO, interconnector owners and other market participants from setting up and operating IT systems and processes. These costs are likely to be highest under 3.1. Under 2B on the other hand, there would be no implementation costs. Further analysis could be undertaken to quantify these costs if 3.1 is adopted.
Security of supply				Operability Risks are associate with the ability to manage and control large rapid system changes in a very short timescale on the Transmission system. The SO has a responsibility to ensure that system can accommodate a wide rage of different sources of energy and balance these Operability Risks against facilitating these energy sources.
Impact on interconnector investment	Limited*	Limited	Limited	The quantitative analysis suggests interconnector revenues could increase slightly with a lower ramp rate. This analysis does not capture the costs of imbalance. However, based on the evidence provided, this is not expected to materially affect investment decisions.
GB CO2 emissions savings	-231,000 tCO2*	-10,000 tCO2	28,000 tCO2	GB carbon emissions increase slightly in 2B and decrease slightly in 3.1 as a result of changes in the generation mix. These changes in carbon emissions are captured at market prices within the estimates of Socio-Economic Welfare. Under the Governments social cost of carbon, these emissions impacts are equivalent to -£2m (2B) and £7m (3.1).

Cost £0-10m | Cost £10-100m | Cost >£100m | Benefit £0-10m | Benefit £10-100m | Benefit >£100m

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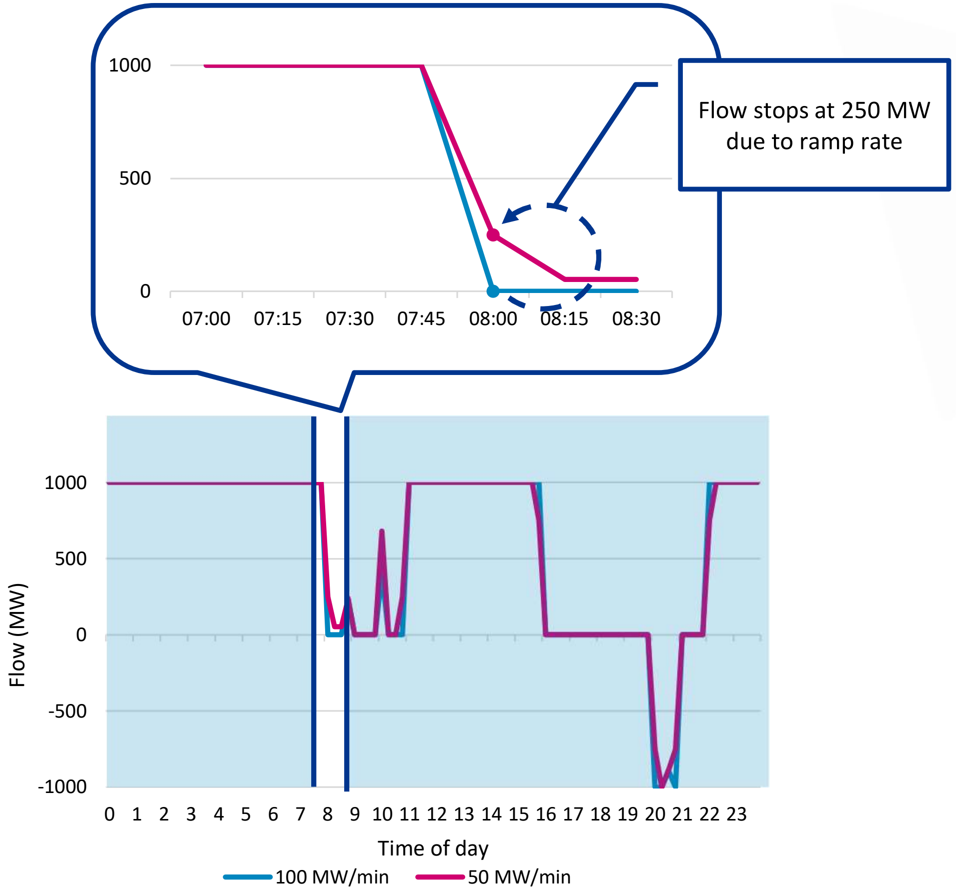
Modelling Outputs | Flow Characteristics

Ramping rates lag changes in flows, but summary flows don't change significantly

One day example of GB – NL interconnector flows



A constrained event

Most events are observed at the beginning of an hour when the model presumes change in demand and renewable profiles

Coupling time periods

Ramping event connects two time periods – the beginning and the end of the event

Possible options to meet the required constraint on GB side

At the begining

- Generators on GB side decrease their output and increase import
- GB price falls

At the end

- Generators on GB side increase their output and decrease import
- GB price raises

Possible options to meet the required constraint on NL side

At the begining

- Generators on NL side increase their output and decrease import
- NL price raises

At the end

- Generators on NL side decrease their output and increase import
- NL price falls

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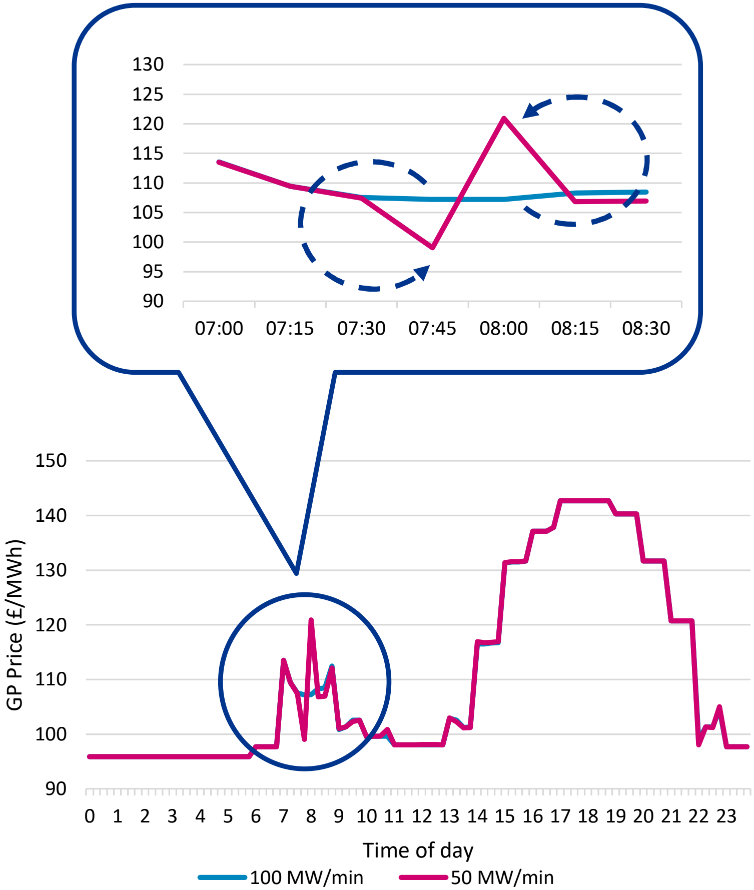
Modelling Outputs | Price Characteristics

Prices form cardiogram curves, but average prices don't change significantly

One day example of GB prices



Prices

In most cases GB price is affected. In the ramping event from 07:45 to 8:00 GB price

- decreases at the beginning of the first time period
- increases at the end of the second time period

Impact on interconnectors

- In Option 2B, Interconnectors are affected during both import and export directions
- In Option 3.1, Interconnectors are mostly affected in export directions

The influence is expressed in terms of when a flow takes place, not in terms of what magnitude the flow has. It results in comparatively same flows between options. blame prices give overall insiginificant changes in interconnectors' revenues.

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Balancing Actions Baseline Results

Our analysis shows that the average cumulative ramp rate increases year-on-year

		2023	2024	2025	2026	2027	2028	2029	2030
Ramp Rate (MW/mins)	0	1806	1900	2187	1967	1981	2094	2393	2585
	0 – 50	2332	2184	1868	2120	1995	1742	1787	1785
	50 – 100	1688	1533	1505	1544	1489	1382	1324	1339
	100 – 150	1087	1015	973	953	915	909	826	754
	150 – 200	713	732	746	692	687	734	638	634
	200 – 250	421	474	512	465	492	530	474	432
	250 – 300	278	352	362	370	448	431	425	409
	300 – 350	151	226	221	233	267	284	256	233
	350 – 400	146	128	155	152	183	216	212	216
	400 – 450	49	83	78	90	95	135	148	134
	450 – 500	89	69	78	90	93	119	115	88
Summary Stats	Avg Ramp Rate	89	97	99	100	106	117	109	104
	Avg Price (£/MW)	£221	£175	£134	£92	£87	£79	£67	£60
	Overall Cost (£)	£388m	£359m	£ 286m	£212m	£228m	£244m	£203m	£168m

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CBA Outputs | Quantitative

Changing GB interconnector ramp rates can be felt across the EU, with changing Carbon emissions

Total Reduction in CO_2 emissions, 000 tonnes	Option 2C vs 2B	Option 2C vs 3.1	Option 2C vs 1A*
GB	-10	28	-231
FR	2	-17	-6
BE	-10	-13	-15
DE	-3	-97	-30
DK	0	-1	-5
NL	-15	-33	-20
Rest of Europe	36	-67	-69
Total	0	-201	-377

