GC0154: Interconnector Ramping Workgroup

Working group session 11

09 05 2023

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Agenda

Agenda Items		
	Introduction	• Team introductions - All
	Project Background	• Project Purpose - Ronan
	Methodology & Outputs	• Outline proposed modelling methodology - Meerav • PLEXOS - Josh • Balancing Actions - Meerav • CBA Outputs – Alex
	Project outcomes and next steps	• CBA Results – Ronan/Alex • Q&A

Project Purpose

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 flow change 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

Methodology

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
- Reserve, Repositioning, Response and Frequency Control actions are considered
- 2022 data was used to determine volume of average action per given flow change magnitude, noting costs would be distorted by market effects
- A strong non-linear correlation (0.98) between I/C cumulative ramp rates and volume (MW) of BOAs + ASDP instructions was found
- 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 ramp estimate

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

We reached agreement on the following options – noting implementation details were agreed out of scope

2C

Baseline: Retain 100MW/min Ramp Rate Limit

- Use existing maximum 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 limit based on flow change size)

- Use existing maximum 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 flow change. All other interconnectors use their default rates (e.g., EWIC, Moyle, NSL).

2B

Static Lower Ramp Rate
(Limit: 50MW/min)

- Change continental interconnector base rate ramp limit to match generators (max 50MW/min)
- All other interconnectors use their default rates (e.g., EWIC, Moyle, NSL).

3.1

Dynamic Ramp Rate Periods
(Limit: 100MW/min <-> 50MW/min)

- Ramp rate changes to meet system needs
- Base maximum 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).

PLEXOS Pan European Day Ahead Model

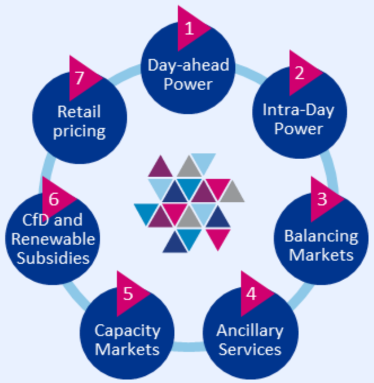
Each option was modelled using our PLEXOS model to provide inputs into the CBA

1 Inputs

- Fuel and carbon prices
- Detailed plant level database
- Cost and characteristics for generic plants
- Baringa new build assumptions
- Interconnector ramp rates
- Interconnector capacity

2 Modelling Engine

- 15-minute dispatch, least-cost optimisation framework using the PLEXOS platform
- Optimisation of operational constraints including start costs, ramp rates, heat rates
- Multiple weather and demand years
- Maintenance scheduling and unplanned outages



3 Outputs

- Capacity and demand
- Power prices
- Capacity and system service prices
- Generation schedules
- Emissions
- Wholesale revenue and gross margins
- Dispatch costs
- Curtailment

- We utilised our Day Ahead PLEXOS Pan European model to simulate hourly interconnector flows and wholesale prices alongside other key CBA inputs from 2023-2030
- This model utilised a set of input assumptions on future generation build, interconnector capacity and characteristics of plant. For further information on the assumptions used in the reference case please see Appendix C
- The model was run at 15-minute resolution rather than hourly resolution to adequately detect the effect of changing the ramp rates on intercontinental interconnectors
- We kept demand, wind, and solar profiles to be flat within hours, however outages could happen any time
- Further analysis was undertaken to check that running the model at 15-minute resolution is reflective of an hourly market

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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 interconnector 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
- From this data we determined the equation of a non-linear relationship between ramp rate and Repositioning, Reserve, Frequency Control and other short term energy actions
- We further developed a methodology to calculate long-term reserve (where actions needed to be taken between 15-45 mins before an I/C flow change) using operational experience
- We determined future Balancing action cost through:
  - Calculating average cumulative ramp rate for every hour between 2023-2030
  - Applying our non-linear relationship from Repositioning, Reserve, Frequency Control and other short term energy actions and our equation for reserve
- 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)*

CBA Framework

We analysed a 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 e.g. changes in emissions (MtCO2/yr)	PLEXOS modelling plus HMT Green Book carbon values
Other non-quantified impacts	Other costs and benefits e.g. impacts on security of supply and imbalance costs	Qualitative review and analysis

Monetised, quantified and qualitative impacts for all options, with ranking/scoring of combined impact for each option

Sensitivity analysis: how sensitive is the recommended option to changes in high impact assumptions?

Recommended option takes into account monetised, quantified and qualitative evidence, and proposals for refining the evidence base

Switching analysis: are qualitative impacts sufficiently material to outweigh quantified impacts?

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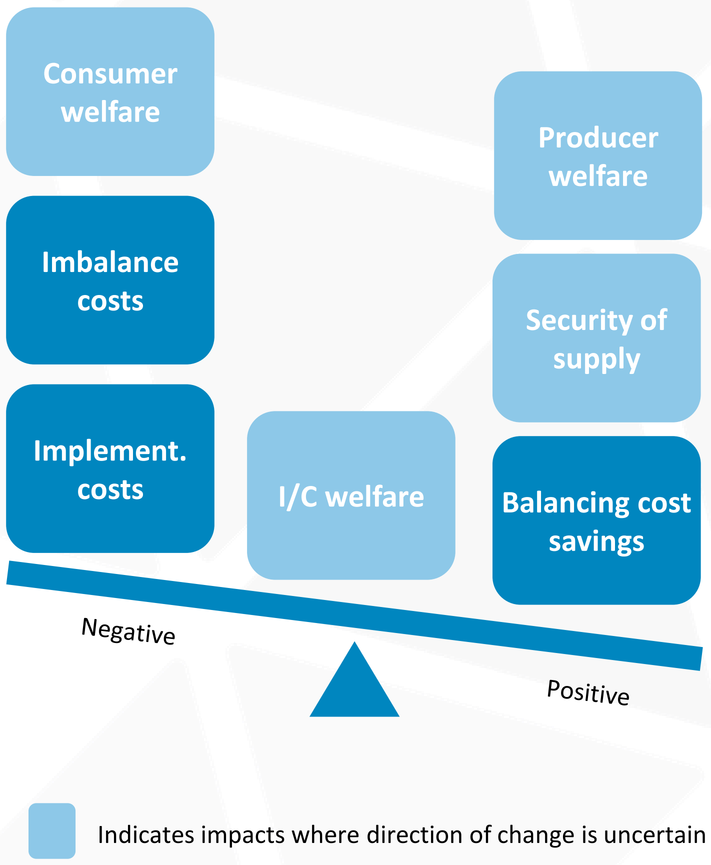
Expected impacts in the CBA

The choice of options depends on the balance between balancing cost savings and non-monetised costs

- The outcome of the CBA is likely to rest on the balance between the balancing cost savings and security of supply benefits from moving to a lower ramp regime, and the increase in implementation costs and any welfare or cost impacts on interconnectors.
- Based on historic data, the balancing costs savings from moving to a lower ramp rate could be significant and are likely to be the largest overall impact in the CBA. A lower ramp rate could also provide security of supply benefits by reducing operability risks, although these are not quantified in the CBA.
- Introducing ramp management or a dynamic ramp rate regime would require major IT changes for interconnectors and the ESO, which would have a negative impact on the CBA for those options. However, the implementation costs for moving to a static 50 MW/min ramp rate would be close to zero.
- Through the discussion with the Working Group, interconnector owners have flagged that a lower ramp rate could result in additional imbalance costs. This would result in a negative impact on the CBA for lower ramp rate options.
- Interconnector welfare more generally could increase or decrease in a given period, and the net effect overall is unclear. A lower ramp rate could lead to price divergence between connected markets as interconnectors are less able to respond to sudden price changes. However, prices could also converge if the lower ramp rate results in interconnectors ramping earlier where that maximises their revenue under a lower ramp rate.
- The impact on producer and consumer welfare is less clear cut and depends on the relative change in wholesale electricity prices from moving to a lower ramp rate. However, in general, these impacts would be expected to move in opposite directions, with an increase in prices reducing consumer welfare and increasing producer welfare, potentially cancelling one another out.

Expected impact of a lower ramp rate



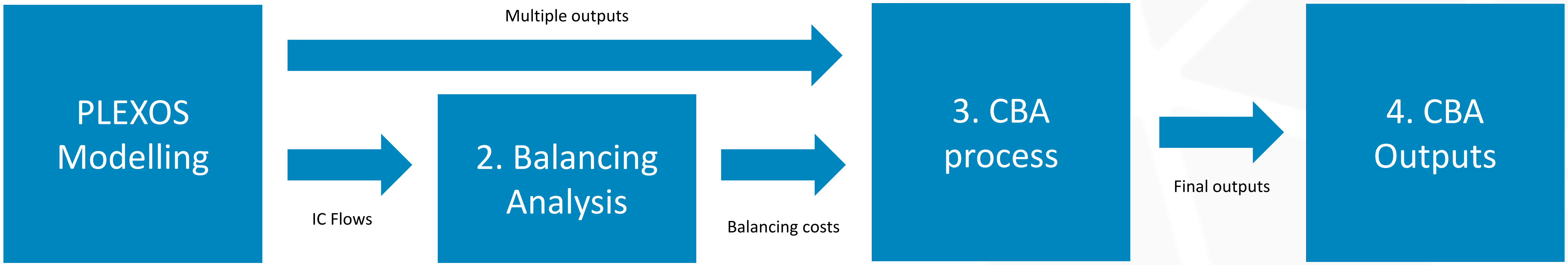
Modelling + CBA Outputs

Section Overview

In the following sections we work through the Methodology presented earlier by stepping through some examples to illustrate our CBA inputs

Section	Description	Pages
1. PLEXOS modelling	• PLEXOS price impacts • PLEXOS flow analysis	Pg 14-16
2. Balancing analysis	• Exemplar I/C flow change cost analysis • Analysis into how average cumulative ramp rate changes from 2023 – 2030	Pg 17-18
3. CBA outputs	• Overall monetised impacts analysis • Non-monetised impacts analysis • Sensitivities analysis	Pg 19-20

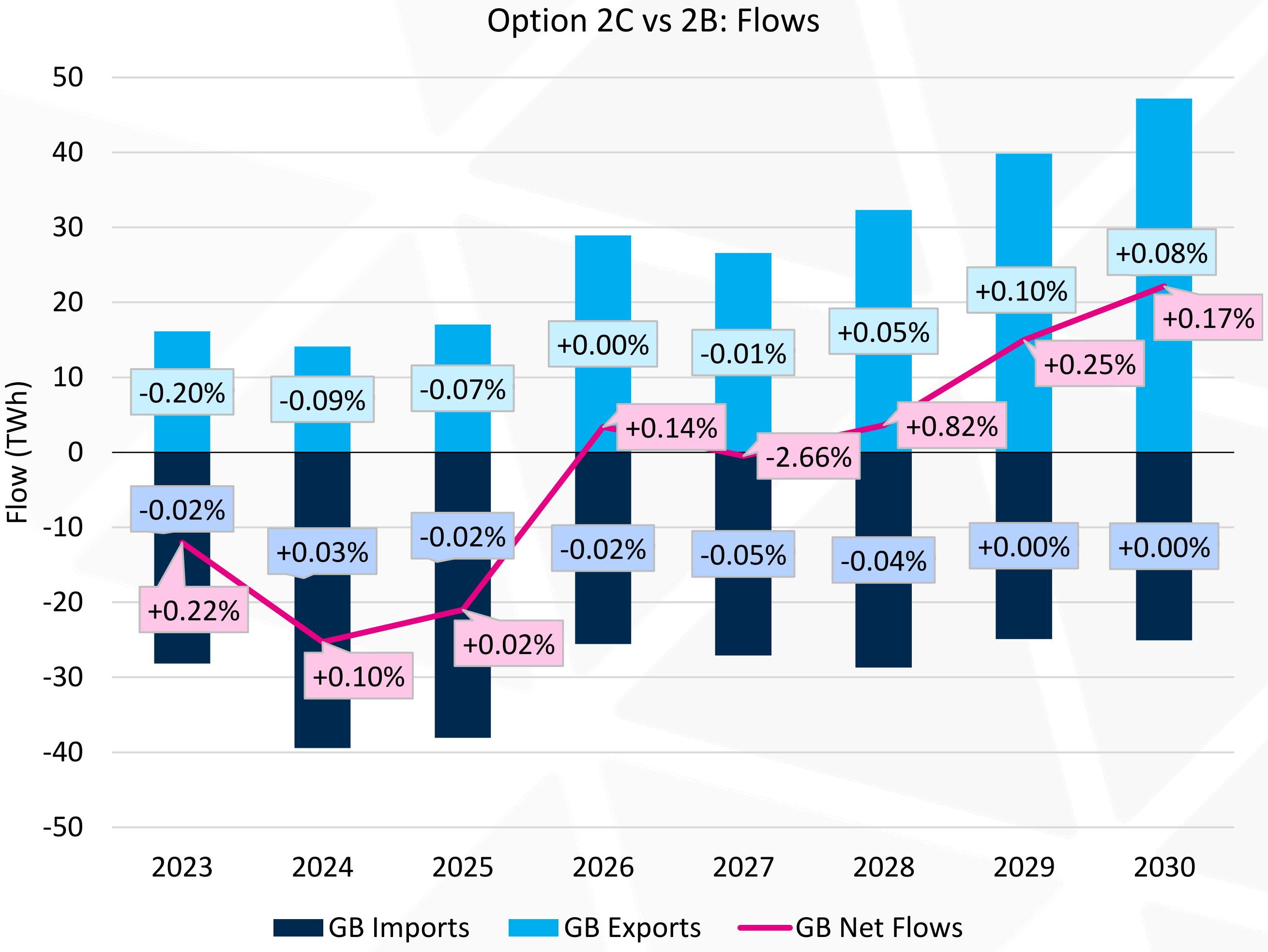
Graphical Overview of the flow of data within the Methodology that are described within this section



1. Modelling Outputs | Flow impacts

A key part of the analysis is to understand the impact of the change in ramp rate on interconnector flows and revenues – our analysis suggests that moving from 100MW/min to 50MW/min could have a small impact on total GB interconnector flows

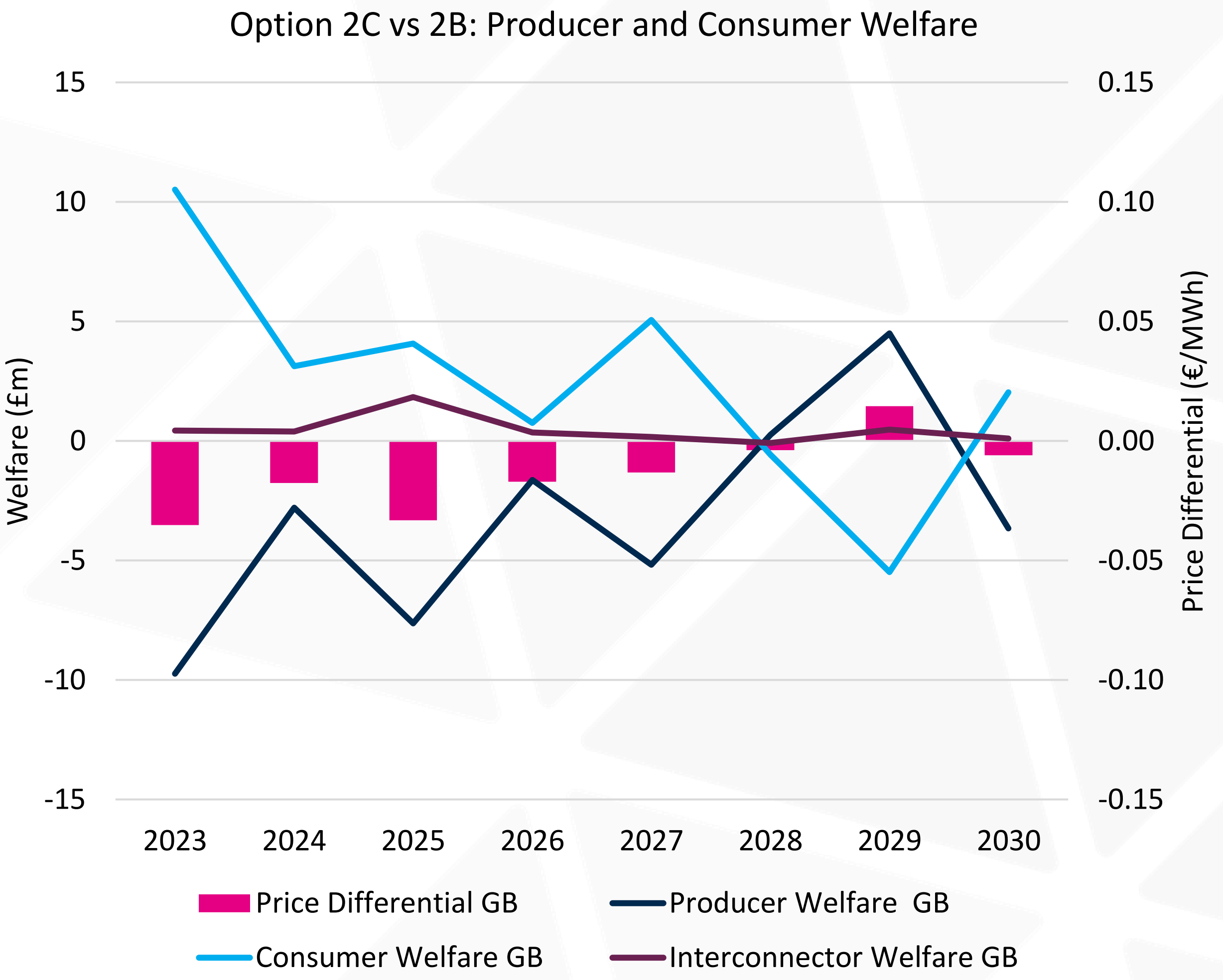
- In the chart on the right imports are denoted as negative and exports are denoted as positive. Negative net flows indicate GB is net importer whilst positive net flows indicate GB is a net exporter.
- The data labels show the differences between the 50MW/min option (2C) and the base 100MW/min option (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.



1. Modelling Outputs | Price impacts

The analysis suggest that the impact of a slower rate could have a marginal impact on GB wholesale prices and interconnector revenues, but these impacts appear to me very small

- 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 2028, 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.



2. Balancing Analysis | Example Flow

Applying our methodology to an example interconnector flow change

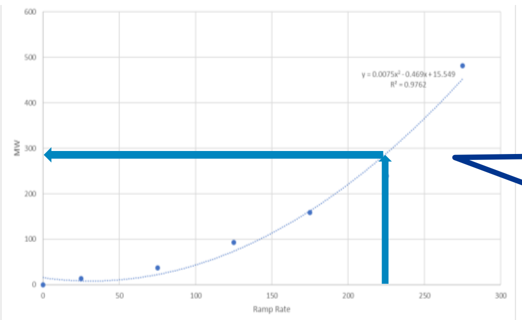
This slide illustrates through an example how we take PLEXOS flow outputs and apply our two methodologies to determine overall Balancing actions and their associated costs.

Step 1: Analyse PLEXOS hourly flow changes

From a given PLEXOS hourly output we calculate the flow change and associated average cumulative ramp rate

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

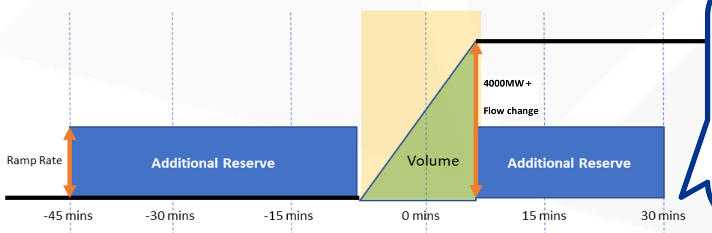
Step 2A: Calculate Repositioning, Response, Frequency Cont. + other volumes



We calculate Balancing action volume required using the established 2022 relationship between cumulative ramp rates and Balancing actions taken

Total volume: 280MWh

Step 2B: Calculate Reserve volumes



We apply a formula to calculate the length of time reserve is required based on flow changes (see Appendix B)

Total volume: **1.25hrs * 225 MW/mins = 281 MWh**

Step 3: Apply hourly wholesale price to then Balancing volume required to calculate overall cost

569 MWh * £200/MW => £113,800

See detailed methodology in Appendix B

2. Balancing Analysis | Baseline Results

Our analysis shows that the average cumulative ramp rate (MW/min) increases from 2022 to 2030

This slide illustrates the cumulative ramp rate of our counterfactual calculated from PLEXOS hourly flows broken down by years. It shows that the average cumulative ramp rate increases from 2023

1. Ramp rate calculated from cumulative PLEXOS continental interconnector modelled flows

2. Each number represents number of hourly flow changes a year that fall within a certain ramp rate

3. Overall we see an increase in the average cumulative ramp rate experienced

	MW/min	2023	2024	2025	2026	2027	2028	2029	2030
Ramp Rate (MW/mins)	**0**	1806	1910	2187	1967	1981	2045	2393	2585
	0 – 100	4020	3699	3372	3664	3484	3169	3111	3124
	100 - 200	1800	1740	1720	1645	1602	1659	1464	1388
	200 - 300	699	839	874	835	940	940	899	841
	300 - 400	297	362	376	385	450	522	468	449
	400 - 500	138	146	156	180	188	240	263	222
	500 - 600	0	64	75	84	115	125	100	85
	600 - 700	0	0	0	0	0	60	62	66
	700 - 800	0	0	0	0	0	0	0	0
Summary Stats	**Avg Ramp Rate**	89	97	99	100	106	117	109	104
	Wholesale Price (£/MW)	£221	£175	£134	£92	£87	£79	£67	£60
	Overall Cost (£)	£387m	£360m	£286m	£212m	£229m	£245m	£204m	£168m

4. By 2030 there is an overall 9% increase in time periods where interconnectors do not change their position.

5. Yet similarly by 2030 there is ~45% increase in ramp rates above 300MW/min

6. Whilst the average ramp rate rise from 2023 - 2030, overall cost falls due to modelled lower wholesale prices.

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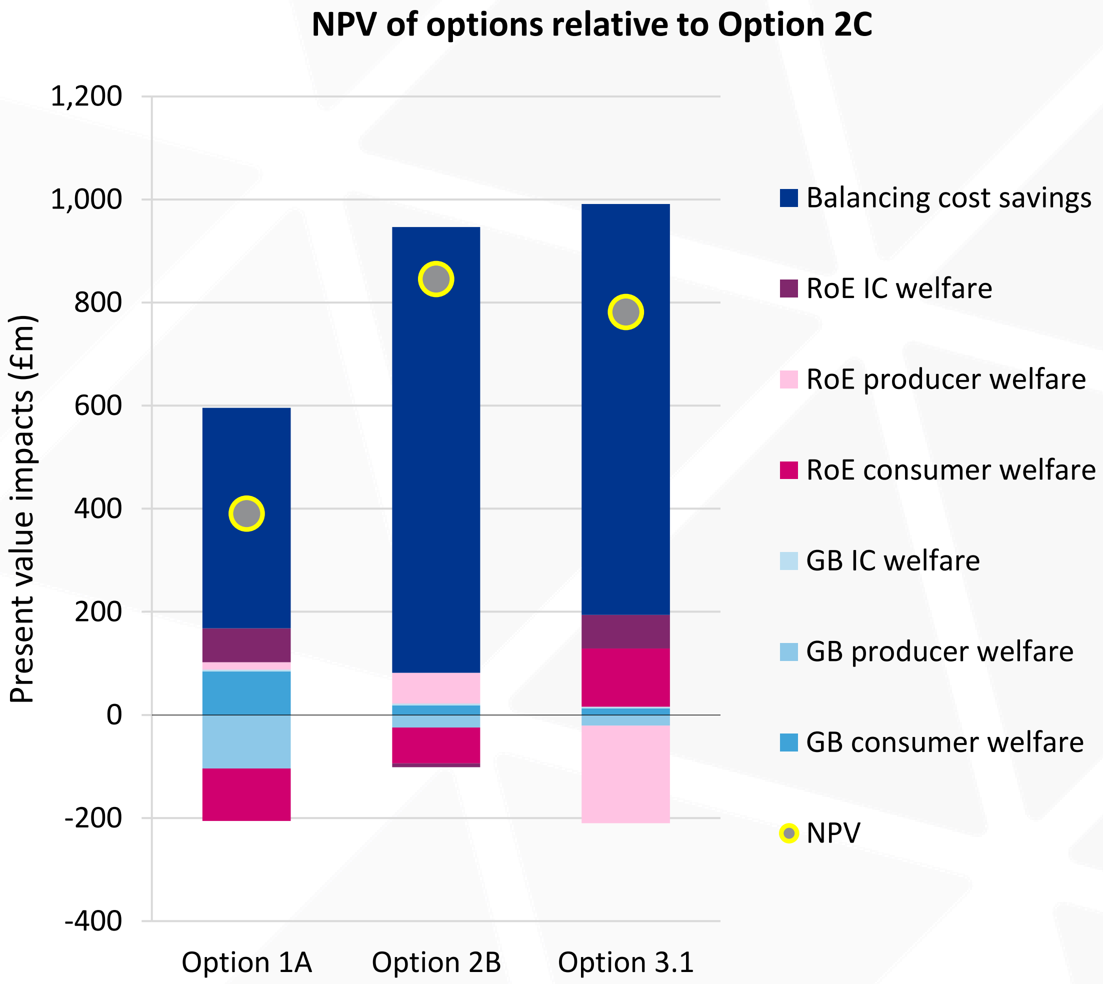
3. CBA Outputs | Monetised impacts

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 £845m , introducing a dynamic ramp rate (3.1) results in a net benefit of £781m and moving to a ramp management option (1A) results in a net benefit of £390m.
- 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. These impacts are marginal, with producer welfare being equivalent to around 0.01-0.03% of overall 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.



3. CBA Outputs | Qualitative Impact Assessment

Further analysis of qualitative costs and benefits

Qualitative	Description	Option 1A	Option 2B	Option 3.1
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	Major IT systems changes to all parties	No change to current IT systems	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.	Largest positive impact on GB IC revenues	Positive impact on GB IC revenues	Very slight positive impact on GB IC revenues

Security of Supply (SoS)

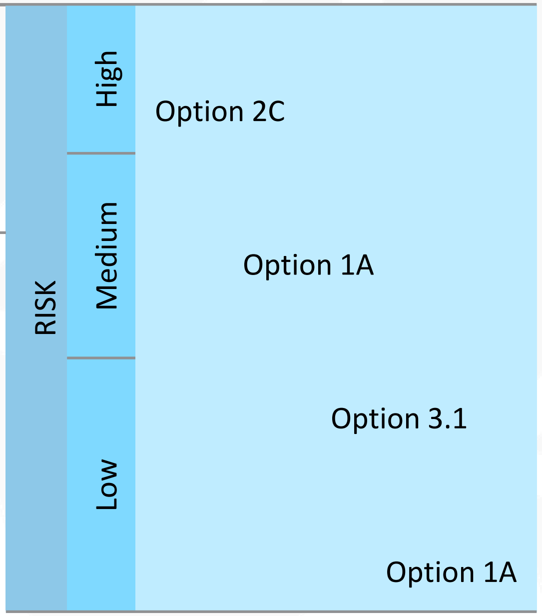
The Operability Risk is a summary of operational challenges which increase the risk to violations of the SQSS, i.e., likelihood of deviation outside of statutory / operational standards (namely voltage and/or frequency excursions). This marker is qualitative instead of quantitative, as for the same operational conditions, there would be a higher / lower risk of deviation, but no monetary value. Due to the speed of the change vs. time to act to control the voltage and/or frequency, the order of probability is from high to low.

Voltage excursion sequence of events:

- Rapid system flow changes lead to rapid changes of active and reactive power flows across the super grid, especially in the south coast.
- The voltage levels in the southeast change accordingly.
- Timely sequential action is paramount to avoid voltage excursions.

Frequency excursion sequence of events:

- Rapid system flow changes creates an overall active power imbalance.
- The national frequency changes accordingly.
- Timely sequential action is paramount to avoid frequency excursions.



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

Results

CBA Results

Qualitative costs and benefits are unlikely to outweigh the balancing cost savings from all options analysed

Cost or benefit	1A: Ramp managmt.	2B: Static lower ramp	3.1: Dynamic ramp	Comment
GB consumer, producer and IC welfare	-£16m	-£2m	-£5m	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	+£428m	+£865m	+£797m	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	-£22m	-£17m	-£10m	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	Medium Risk	Low Risk	Medium/ Low Risk	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	18,000 tCO2	17,000 tCO2	46,000 tCO2	GB carbon emissions reduce slightly in 2B and 1A and a larger reduction is seen 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 £5m (1A), £4m (2B) and £12m (3.1).

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

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