Cost Benefit Analysis of Multi-Region Loose Volume Coupling (MRLVC)

The EU and UK TSOs MRLVC group

Analytical results for publication

April 2021

Important information

Objectives of this pack

- We have carried out a study to inform the Cost-Benefit Analysis (CBA) of the proposed Multi-Region Loose Volume Coupling (MRLVC) that United Kingdom (UK) and European TSOs are required to carry out under Annex 4 of the Trade and Cooperation Agreement between the UK and the European Union (EU).

- There are four final deliverables to this study
  - Short written report summarising the main findings of the CBA and providing the context for the analytical results
  - **Slidepack containing the main analytical results** (this pack, which should be read alongside the short written report)
  - Slidepack containing results from wholesale market modelling using the SDAC Simulation Facility (SF)
  - Slidepack containing results from wholesale market modelling using the TheMA European power market model

Contents

Framework for this CBA study

- The TCA Annex sets out a requirement for the TSOs to carry out a CBA of the proposed MRLVC arrangements. However, the TCA does not specify the precise purpose of the CBA, the methodology, or how it will be used.

- A ‘standard’ CBA is not feasible – namely the evaluation of a well-developed solution prior to approval
  - very tight timescales available for this work
  - uncertainty about important factors, such as process and accuracy of the forecasts for flows from the IEM into Bordering Bidding Zones (BBZ) connected to GB

- Therefore, the focus of this study is on a CBA which can be used to frame the process going forward, establishing the conditions for a beneficial MRLVC solution on a border-specific basis.

Constraints set by TCA Annex

1. **Data restriction**: only Bordering Bidding Zone (BBZ) and GB order books can be included in the MRLVC
   - This requires EU TSOs to provide forecasts for the BBZ commercial flows within IEM
   - The method and accuracy of this BBZ flow forecast is not known, and while it will be a critical feature of the MRLVC it is outside the scope of the study
   - Alternative volume coupling solutions are inconsistent with the TCA Annex

2. **Process restriction**: MRLVC process/algorithm should be distinct from SDAC
   - Rules out operationally integrating the MRLVC and SDAC matching processes
   - Does not explicitly prohibit use of Euphemia software in MRLVC

Development of MRLVC options

- We have developed high-level MRLVC options (and a counterfactual) for assessment versus CBA framework
  - Minimum requirement for MRLVC option is to be compliant with the TCA Annex
  - Informed by our preliminary assessment and the feedback we have received; in particular concerns expressed about the possible impact of the Common Order Books option on SDAC

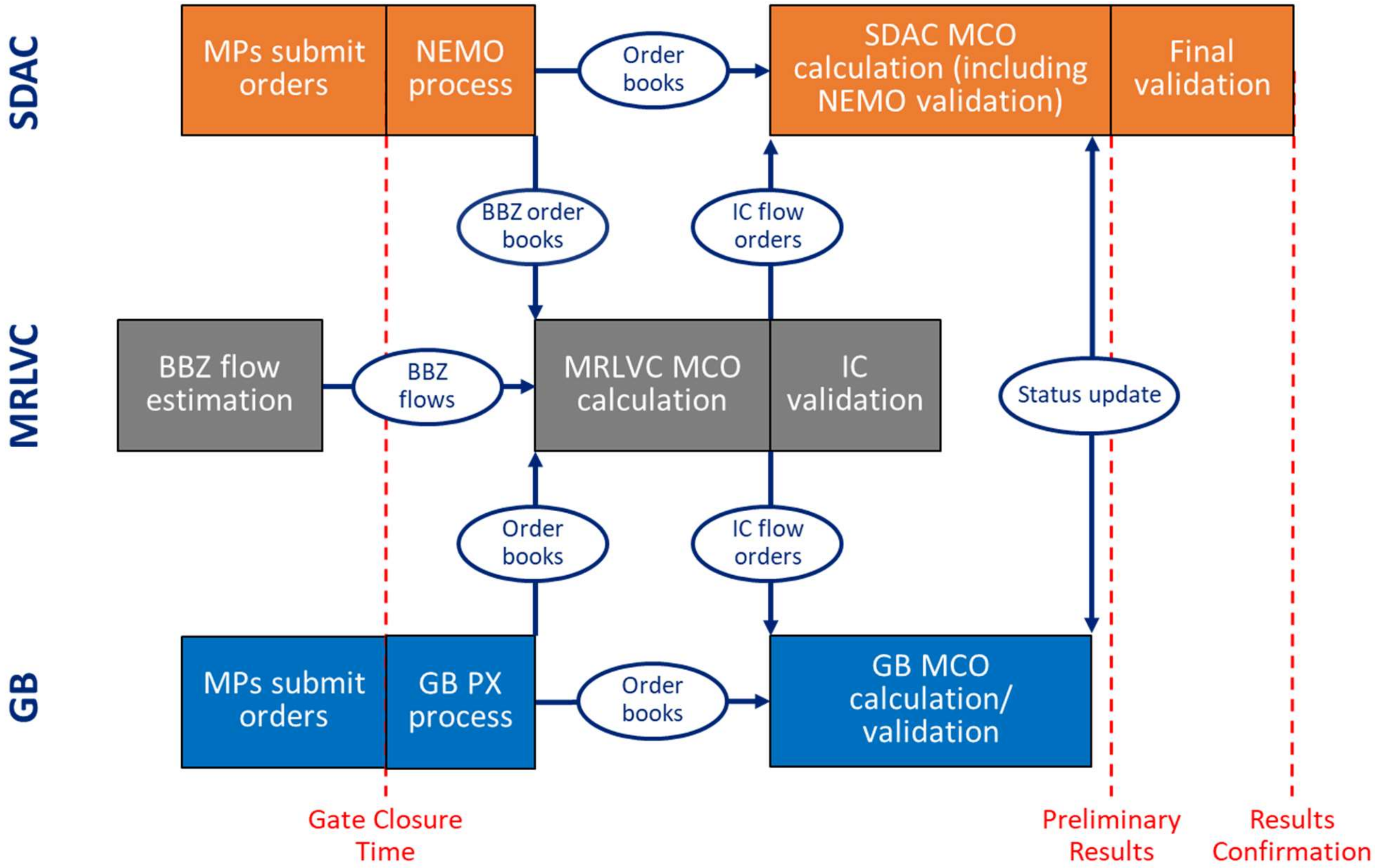
- In designing MRLVC options, we have focused on the most important choices/trade-offs for whether and how to proceed with LVC implementation
  - These differences should be captured in the assessment against the agreed criteria in the CBA framework

MRLVC options

- **Common order books option**
  - Use of final BBZ order books in MRLVC
  - Single GB price
  - Support to current products (e.g. 'complex orders')
  - MRLVC-determined flows used as price taking orders

- **Preliminary order books option**
  - Use of preliminary BBZ order books in MRLVC
  - Single GB price
  - Support to current products (e.g. 'complex orders')
  - MRLVC-determined flows used as price taking orders

Common Order Books Timeline



Preliminary order books

- In order to minimise impact on SDAC, the MRLVC will start earlier, using whatever order books have been received by 11:45* in the bordering BZs (and final order books from GB)

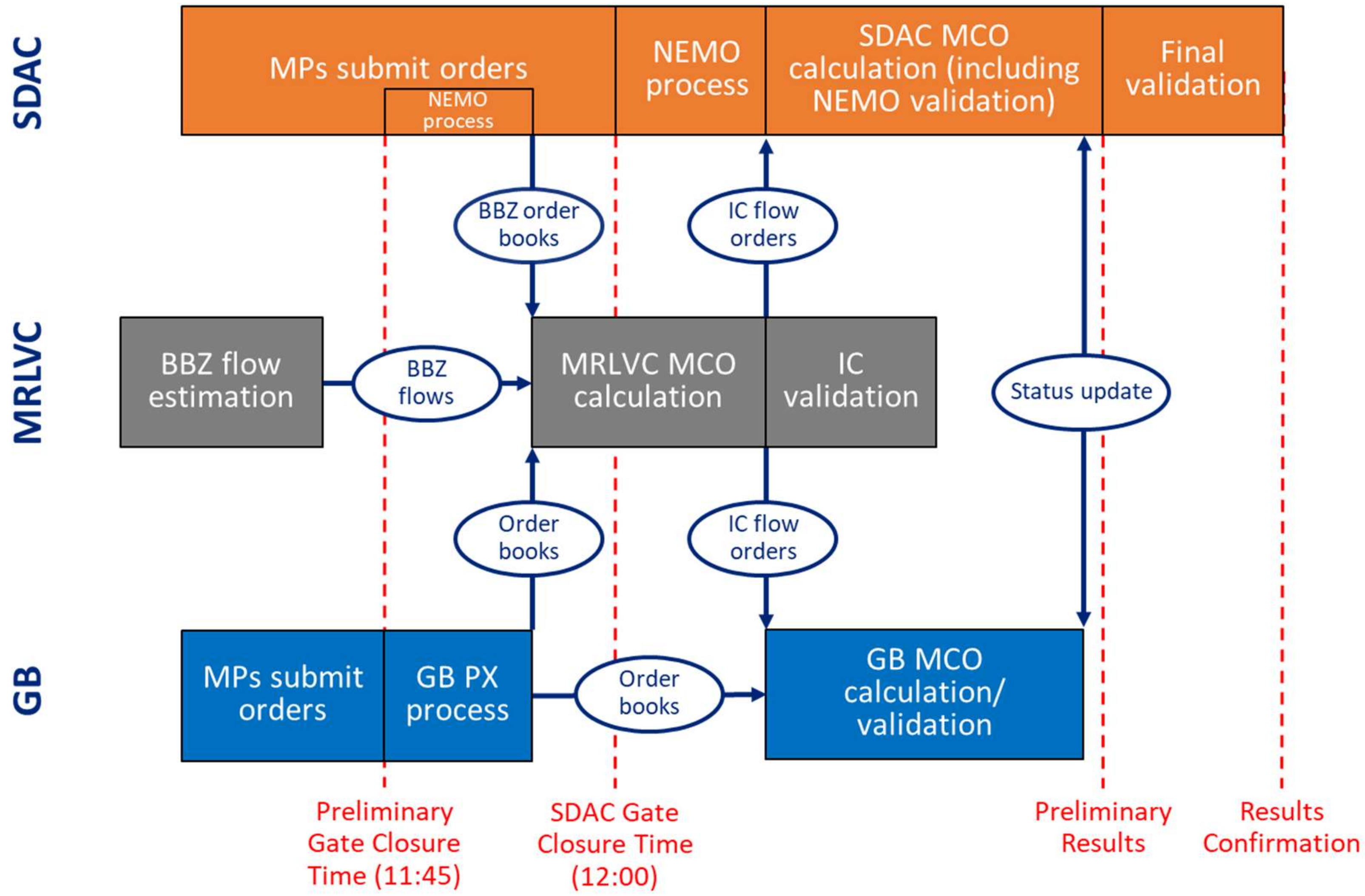
- Market participants in SDAC BBZs are free (as they are today) to submit new orders or amend orders already submitted up until SDAC gate closure at 12:00 CET

- GB gate closure would be at 11:45* CET

- MRLVC results need to be available to SDAC ahead of 12:10 (normal start of SDAC computation) – implying no delay or change to SDAC process

* times shown are indicative; they depend on the MRLVC processing time and the speed with which results can be transferred to SDAC MCO

Preliminary Order Book Timeline



Assessment criteria

	High-level MRLVC options		Counterfactuals		
Aspect	Common Order Books	Preliminary Order Books	Explicit Auctions	ID Price Coupling (**SEM-GB**)	Separate DA Coupling (**NSL**)
Consumer and producer welfare	Mixture of qualitative and quantitative assessment (using wholesale market simulation tools, and historical analysis)				
Interconnector revenues	Mixture of qualitative and quantitative assessment (using wholesale market simulation tools, and historical analysis)				
Impact on CO2 and low carbon targets	Mixture of qualitative and quantitative assessment (using wholesale market simulation tools)				
Meeting market needs	Mixture of qualitative and quantitative assessment (using wholesale market simulation tools)				
Compatibility with IC technical requirements	Qualitative assessment				
Operational complexity of allocation process	Qualitative assessment				
Futureproofing	Qualitative assessment				
Operational impact on SDAC	Qualitative assessment				
Roles and governance	Qualitative assessment				
Ease/speed of implementation	Qualitative assessment		*Not relevant*		
Cost of implementation	Mixture of qualitative and quantitative assessment (using historical analysis)				
Cost of operation					

No significant issues — Material issues, potentially manageable — Severe issues likely to be challenging to resolve

SDAC Simulation Facility

- The SDAC Simulation Facility (SF) allowed allowed us to model the SDAC and GB markets using actual order books (OBs) and ATCs whilst testing the impact of new interconnectors (ICs).
- In order to use a consistent grid topology (excluding any new ICs), we used the period from 4 July 2019 (CWE MNA go-life) to 3 June 2020 (Nordic MNA go-life) – during which GB was part of SDAC
  - There were two days not used in that period: 5/2/20 (decoupling) & 22/5/20 (technical reasons)
  - Selected period of 334 days with constant grid topology
  - To produce the annual values, the SDAC SF results are scaled up by a factor of 365/334
- We added these ICs in the Simulation Facility analysis: IFA2, Eleclink, NSL, Viking Link, GreenLink
- The SDAC SF analytical annex slidepack (provided alongside this pack) contains much more detail on the approach and results from the SDAC SF

TheMA Power Market Model

- We used the TheMA Power Market model for simulations in 2022 and 2025
  - Highly sophisticated power market simulation model using advanced optimization techniques
  - Large active user-group of license holders
  - Continuously updated with latest data
- We used the TheMA Power Market ‘Best Guess’ scenarios (February 2021) for 2022 and 2025

- The THEMA analytical annex slidepack (provided alongside this pack) contains much more detail on the approach and results from the TheMA model.

Impacts tested with market simulation tools

Issue tested	How investigate in quantitative analysis?
Accuracy of BBZ flow forecast methodology used in MRLVC	We proxied BBZ flow forecast errors by applying a ‘disturbance’ to supply/demand in Germany (DE/LU) and NO1. This then fed into an ‘error’ in the expected Net Exports into BBZ used in the MRLVC. The disturbances we applied to DE/LU and NO1 were informed by analysis of the standard deviation in net export position in the two zones (in the historical data for the period analysed in the SDAC SF)
Inefficiencies in net nominations under explicit capacity allocation	We estimated net nominations based on ‘expected price differences’ between GB and each BBZ (using an observed relationship between price differences and IC utilisation under explicit allocation on the German-Swiss border). Expected price differences were set at the level produced under a reference case of fully efficient volume coupling. ***The SDAC SF and THEMA analytical annexes describe the analysis and modelling of explicit capacity auctions in more detail.***
Changing market conditions, including price convergence	We analysed results on different links, and under different market conditions (e.g. 2019-2020, 2022 and 2025).
New ICs between GB and IEM	We used different sets of assumptions on the new ICs to GB that may be built out to 2025.

Accuracy of BBZ flow forecasts

- Disturbances tested in SDAC SF analysis
  - 6 cases (3 sizes of error in each direction)

Disturbance	Low Demand (LD)	Low Supply (LS)	Medium Demand (MD)	Medium Supply (MS)	High Demand (HD)	High Supply (HS)
	0.5*historical standard deviation		historical standard deviation		2*historical standard deviation	
NO1	600	600	1200	1200	2400	2400
DE/LU	2250	2250	4500	4500	9000	9000

- 3 sets of blended results by assigning different cases to different days

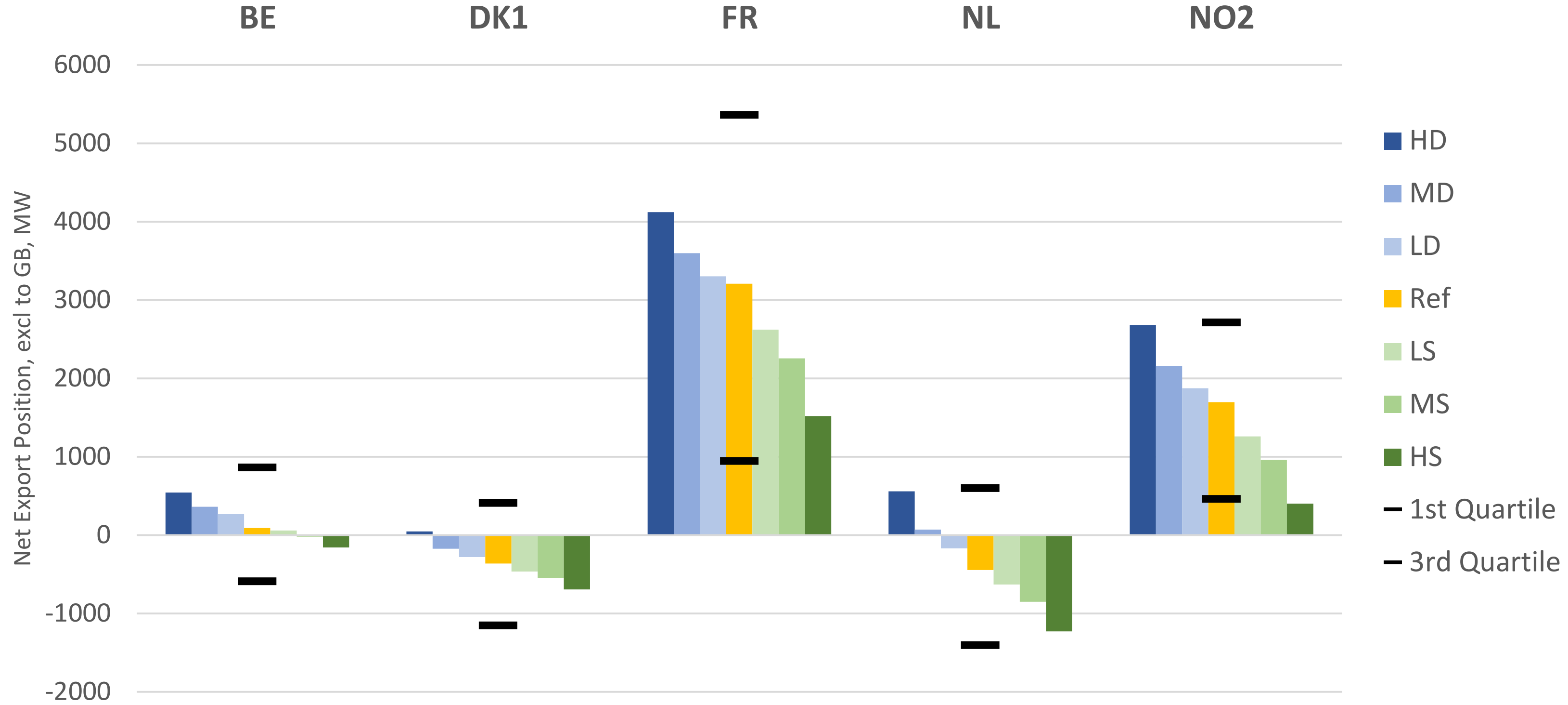
Forecaster	Ref	LD	LS	MD	MS	HD	HS
Perfect	100%	0%	0%	0%	0%	0%	0%
Bad	14%	14%	14%	14%	14%	14%	14%
Worst	0%	0%	0%	25%	25%	25%	25%

- Disturbances in TheMA Power Market model (2022, 2025)
  - “Small forecasting error”: demand perturbation in NO1 and DE/LU of +/- 600 MW and +/- of 2250 MW respectively (i.e. half of the standard deviation)
  - “Moderate forecasting error”: demand perturbation in NO1 and DE/LU of +/- 1200 MW and +/- 4500 MW (i.e. the standard deviation)
  - Direction of error alternates on weekly basis in order to ensure feasible water values in the market modelling
  - It was not possible to apply the High disturbance cost in TheMA model (as explained in detailed analytical annex for THEMA modelling)

Impact on BBZ flow forecasts

Under MRLVC, the IEM TSOs will be required to forecast each BBZ's **hourly Net Export** (NEX) position within the IEM (excluding flows to GB)

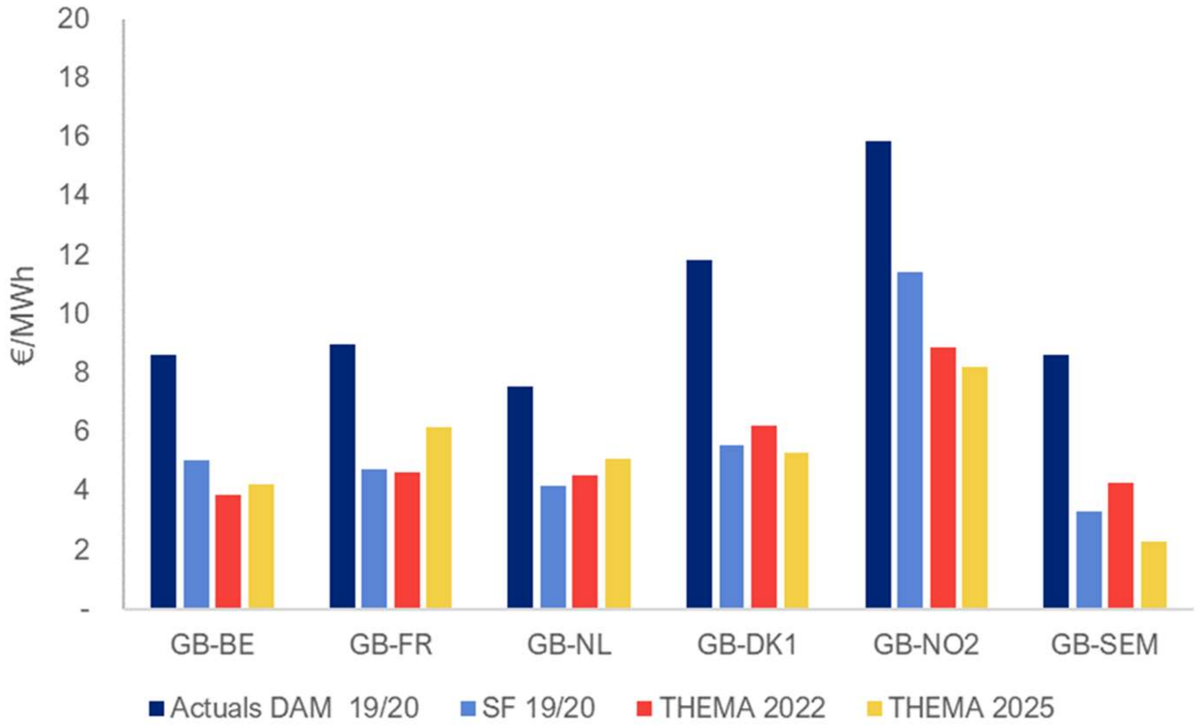
Comparison of the average NEX in the SF cases to average NEX seen in the Reference case (perfect volume coupling), and to the upper and lower quartile values for all the hours in the Reference case
Note: NEX=0 on SEM in all scenarios



The DE/NO1 perturbation approach has given a broad range of impacts on the individual BZ NEXs in NL and NO2, and to a more moderate extent in BE, DK and FR

Changes in market conditions

Absolute average price difference between BBZ and GB



- Differences between Actuals and SF reflect impact of additional IC assumed in SF analysis (IFA2, Eleclink, NSL, Viking Link, GreenLink)
- THEMA analysis based on input assumptions as of end of January 2021 (as discussed further in detailed analytical annex for TheMA modelling)

Assumptions about IC build

GBR -To Zone	IC	Capacity [MW]	THEMA 2022	THEMA 2025	SDAC SF analysis
BEL	NEMO	1000	Yes	Yes	Yes
DK1	Viking Link	1400	No	Yes	Yes
FRA	IFA1	2000	Yes	Yes	Yes
FRA	IFA2	1000	Yes	Yes	Yes
FRA	Eleclink	1000	Yes	Yes	Yes
IRL	EWIC	500	Yes	Yes	Yes
IRL	GreenLink	500	No	Yes	Yes
NIR	Moyle	500	Yes	Yes	Yes
NLD	BritNed	1000	Yes	Yes	Yes
NO2	NSL	1400	Yes	Yes	Yes

Interpretation of quantitative analysis

- The assessment should not be seen as a simple numerical exercise because the interpretation of quantitative results must take into account limitations of the analysis
  - sensitivity of results to different market conditions
  - not estimating how inaccurate BBZ NEX forecast methodology would be
  - for MRLVC, only testing errors in BBZ NEX forecast that are correlated across BBZs
  - for explicit, testing combined effect across all GB- BBZ links of similar errors in price expectations net nominations
  - computational challenges for solvers when using fixed flow assumptions

- The results from the SDAC SF and THEMA modelling help test the impact of different approaches and assumptions – however, these are **not** designed to provide directly comparable results (e.g. in terms of magnitude)

Detailed design options

To inform the future detailed development of the MRLVC, we also assessed advantages and disadvantages of detailed design features associated with the high-level MRLVC options

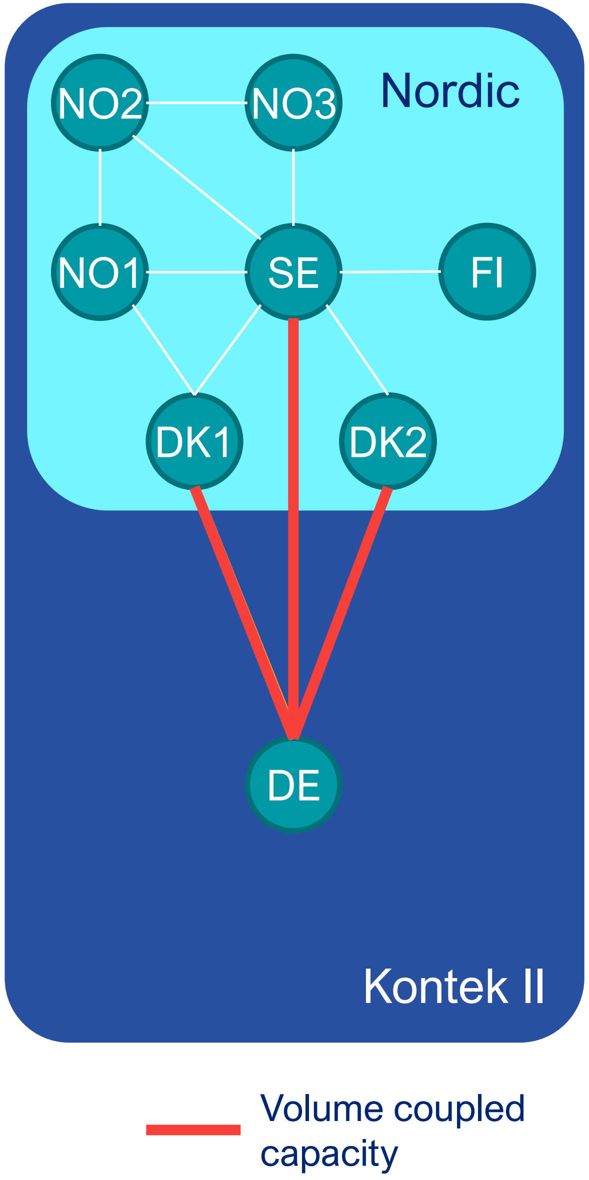
Aspect	Options
1. **Treatment of MRLVC-determined IC flows in SDAC/GB** *(common feature of both assessed MRLVC options)*	a) Price taking orders - base case b) Limit orders in SDAC c) ‘Flexible market coupling orders’ in GB
2. **GB price formation** *(common feature of both assessed MRLVC options)*	a) GB price coupling – base case b) Independent GB price computation
3. **Operational timeline** *(consequence of Common Order Books option)*	a) Earlier gate closure time, at least for GB/bordering BZs b) Delay publication time for SDAC
4. **Process completion** *(issue for both assessed MRLVC options)*	a) MRLVC PTOs are firm, at least for SDAC – base case b) Mutual completion confirmation required from both GB and SDAC before either can report firm results
5. **Long-term rights** *(possible mitigation measures for both assessed MRLVC options)*	a) PTRs: Use-it-or-lose-it (UIOLI) rather than Use-it-or-sell-it (UIOSI) b) PTRs/FTRs: cap payout

Contents

Examples of volume coupling

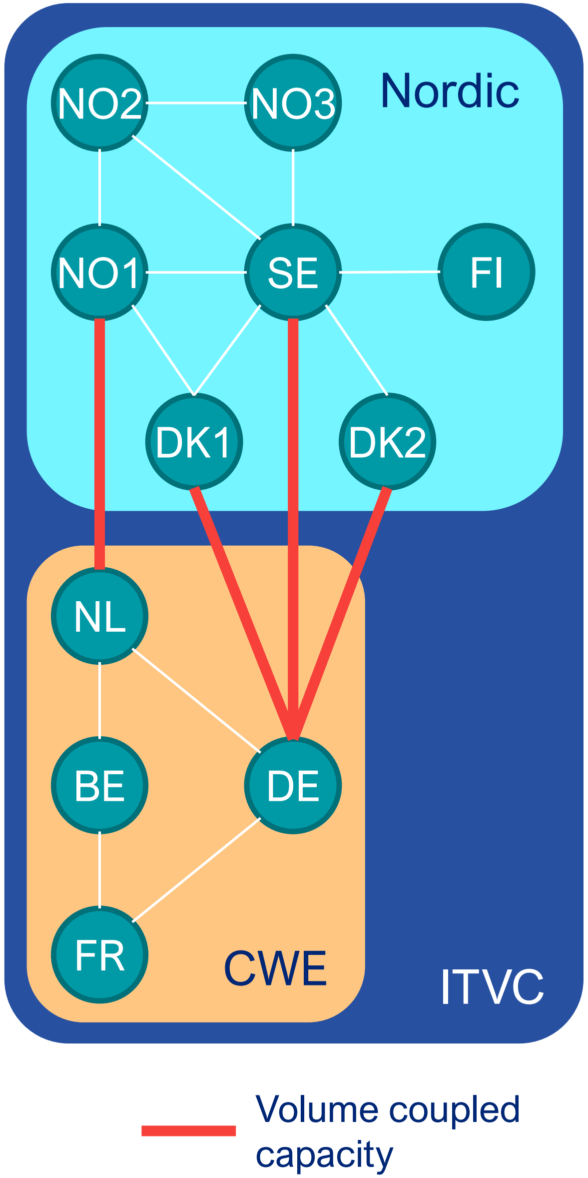
- Volume coupling is generally taken to be a two-step process where
  1. cross-zonal volumes are determined using energy bids in the energy markets ('implicit allocation')
  2. matching of those energy markets (and hence price formation) is undertaken in a subsequent step (which could be a regional price coupling)
- There have been four implementations of volume coupling in Europe:
  - Kontek volume coupling I (Sep – Oct 2008)
  - Kontek volume coupling II (Nov 2009 – Nov 2010), Baltic Cable added May 2010
  - Interim Tight Volume Coupling, ITVC (Nov 2010 – Feb 2014)
  - BritNed embedded solution (Apr 2011 – Feb 2014)
- The literature review has focused on identifying relevant lessons to be learned that are applicable to the MRLVC.
- A more detailed review is available in the annex

Kontek II



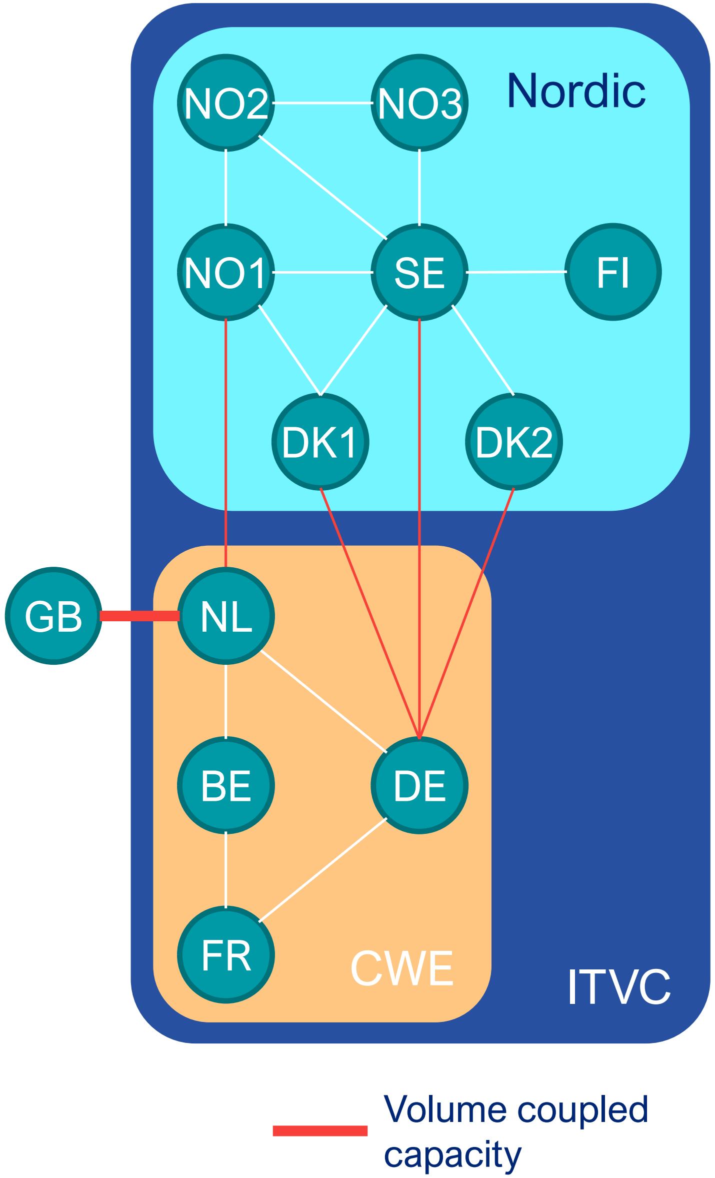
- Relaunched Danish-German coupling with revised algorithm: DK1-DE, Kontek cable (DK2-DE), Baltic (SE-DE, introduced later)
- Operated by EMCC
- Tight volume coupling
  - Common gate closure time
  - EMCC calculates flows using all DE (EPEX) and Nordic (NPS) order books and network data
  - Firm Flow Order on DE; EPEX then matches market
  - EMCC calculates Virtual Area and Fixed Flow Order for DE in Nordic (way to share likely DE price); Nord Pool then matches Nordic region
- Full range of products supported

ITVC



- Replaced Kontek II with launch of CWE
- Operated by EMCC
- Tight volume coupling
  - Common gate closure time
  - EMCC calculates flows using all CWE (Powernext, APX, Belpex) and Nordic (NPS) order books and network data
  - Firm Flow Order on DE and NL; APX or Powernext (alternating MCO) then matches CWE region
  - Confirmation to EMCC
  - EMCC calculates Virtual Area and Fixed Flow Order for DE in Nordic (way to share likely DE price); Nord Pool then matches Nordic region
- Full range of products supported

BritNed Embedded



- Implemented at start of CWE, but not explicitly recognised within ITVC/CWE
- Operated by APX
- Tight volume coupling
  - GB gate closure 5 minutes before CWE
  - GB order book converted into Euro bids and offers on APX NL: net export curve adjusted for BritNed losses and capacity limits
  - APX NL matched according to ITVC/ CWE processes
  - Matched GB orders on APX NL become flows on BritNed; APX matches GB
- Only simple hourly orders supported in GB

Headline messages (I)

- Drivers of volume coupling
  - Address observed (welfare) inefficiencies of explicit allocation
  - Way to link regions with different governance/organisation
  - Mitigate high level of harmonisation and integration needed for price coupling
- Design of volume coupling
  - Examples are all tight rather than loose volume coupling: aim to be as tight as possible
  - MRLVC-style solution for Nordic-CWE considered and firmly rejected in 2009; but without BBZ flow forecast
  - Risks include adverse flows, under-utilisation of IC, and price indeterminacy
- Operational features
  - Sequential process requiring additional time in overall market process
  - Operationally complex because of need to coordinate different computations
  - Need robust design and incident management processes to minimise risk of decoupling

Headline messages (II)

- Performance challenges
  - A **loose** coupling cannot meet the 3 fundamental conditions necessary for an optimal volume coupling solution
    - Volume and subsequent price matching computations use same data, objectives and constraints
    - There is a unique optimal solution, or procedure to select between equals
    - All computations have the time to find the optimal solution
  - Poor design/implementation can seriously harm performance
  - Some inherent exacerbating factors - e.g. block orders
- Performance mitigation
  - Non uniform pricing algorithms could speed up the calculation time
  - Ways have been developed to prevent price indeterminacy on uncongested borders, but probably of limited benefit if the coupling is loose. Mitigating factors – e.g. (quasi) ‘continuous’ net export curves without price verticals
  - MLRVC results could be used to ‘hot start’ SDAC/GB calculations – although would require a highly integrated process and MRLVC is not solving SDAC

Contents

Assessment of two high-level MRLVC options and counterfactual

- **MRLVC common order books option**
  - Use of final BBZ order books in MRLVC
  - Single GB price
  - MRLVC-determined flows used as price taking orders
- **MRLVC preliminary order books option**
  - Use of preliminary BBZ order books in MRLVC
  - Single GB price
  - MRLVC-determined flows used as price taking orders

- **Counterfactual:** this represents current/planned arrangements, rather than an alternative option for implementation to comply with the TCA annex
  - Intraday implicit allocation (price coupling) – **as in place on SEM-GB**
  - Separate day-ahead implicit allocation (price coupling) – **as planned for NSL**
  - Day-ahead explicit allocation – **as in place on all other borders**

Approach to assessment

- The next slide summarises the high-level results of our assessment. The summary table should be read alongside the subsequent slides which provide a more detailed assessment against each element. We have not attempted to give a relative weighting of each factor as different parties are likely to have varying priorities.
- In particular, we highlight that the ‘orange’ score on welfare for MRLVC Common Border Books reflects the current uncertainty about the performance in practice of the BBZ flow forecast.
- Our assessment is informed by a range of evidence; including literature review, results from market simulation models, and historical analysis.
- An assessment of the counterfactual is also presented to show the differences between the three capacity allocation arrangements in the counterfactual
  - The counterfactual represents the current or planned arrangements on each border, none of which represent a solution compliant with the requirements of the TCA
  - The counterfactual arrangements have ‘green’ scores on operational aspects, reflecting that the capacity allocation arrangements in the counterfactual are generally single processes with few interfaces, and no direct interaction with the SDAC process

Summary of Assessment Results

	High-level MRLVC options		Counterfactuals		
Aspect	Common Order Books	Preliminary Order Books	Explicit Auctions	ID Price Coupling **(SEM-GB)**	Separate DA Coupling **(NSL)**
Consumer and producer welfare					
Interconnector revenues					
Impact on CO2 and low carbon targets					
Meeting market needs					
Compatibility with IC technical requirements					
Operational complexity of allocation process					
Futureproofing					
Operational impact on SDAC					
Roles and governance					
Ease/speed of implementation			Not relevant		
Cost of implementation					
Cost of operation					

No issues, or only small issues

Material issues, potentially manageable

Severe issues likely to be challenging to resolve

Consumer and producer welfare

Common Order Books	Preliminary Order Books	Explicit Auctions	ID Price Coupling	Separate DA Coupling
× Loose volume coupling can lead to: • Adverse and suboptimal flows • Loss of producer/ consumer surplus • Transfer of surplus between producers and consumers Severity depends on quality of BBZ flow forecast and level of price spread; effects vary by country ✓ Welfare impacts of poor DA allocation mitigated by ID, but pricing and producer-consumer surplus transfer effects are limited	× Increased risk of inefficient flows and welfare loss compared to Common Order Books due to incomplete order books and potential manipulation ✓ Welfare impacts of poor DA allocation mitigated by ID, but pricing and producer-consumer surplus transfer effects are limited	✓ Efficient flows when price spreads are large or consistently one way × Significant incidence of suboptimal and adverse flows at times of low price spread/variable direction × Less efficient price formation and producer-consumer redistribution ✓ Welfare impacts of poor DA allocation mitigated by ID, but pricing and producer-consumer surplus transfer effects are limited	× Suboptimal DAM price formation/signals × Significant periods with uncongested ID flows even when DAM LAPD was large: implies a loss of potential welfare from trade × ID flows have limited impact on distribution of market welfare benefits (ID market much smaller than DA)	✓ Efficient flows, provided DAMs are accurate (but this is uncertain) × Limited impact on whole GB and NO2 market pricing and welfare due to fragmented DAMs

Possible mitigations:

- Tighter coupling – e.g. better quality BBZ flow forecast

Welfare loss and ID mitigation

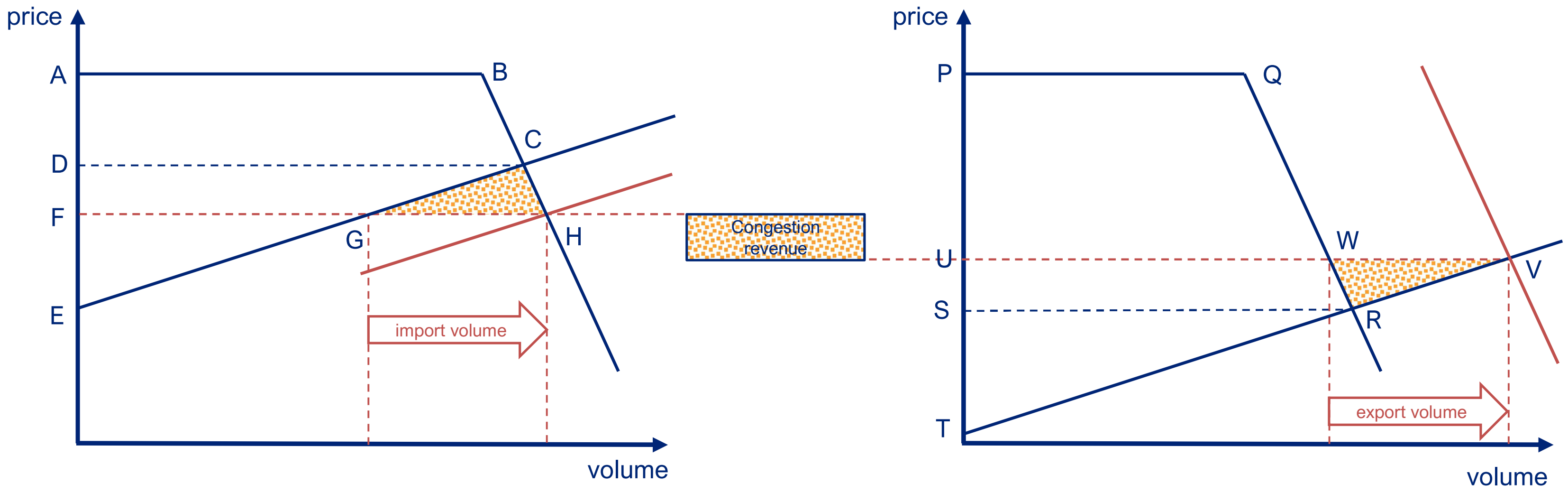
- Poor DA allocation reduces welfare gains from trade, or even cause a net loss in overall welfare compared to no trade (for example, if there are flows-against-price-difference)
- ID allocation of capacity may be able to correct the overall welfare resulting from inefficient DA allocation, achieving (near) optimal overall welfare gain provided that
  - The optimal generation mix runs – but some generators may not be flexible and able to respond to ID signals
  - The optimal demand is served – but some consumers may not be flexible and able to respond to ID signals
  - There is adequate depth/interest in the ID markets to achieve optimal use of interconnection capacity
  - No constraining Intraday Transfer Limits, which would affect large changes of flow
- ID allocation is unlikely to mitigate the distributional effects of poor DA allocation
  - Transfers of surplus from producers to consumers in the importing market (due to lower prices), and vice versa in the exporting market, are significantly reduced due to the relative size of the ID markets compared to DA
  - TSO revenue is likely to be less overall, given the weaker price spreads (implicit auctions) and prices for capacity (explicit auctions) observed in ID markets compared to DA – implies a transfer from TSOs to traders

Economic Welfare from Coupling

Net economic welfare gain

Importing Market

Exporting Market



- Isolated market price, D decreases to F
- Consumer surplus: increases by DCHF
- Producer surplus: reduces by FDCG
- Overall surplus: increases by CHG
- Transfer producer to consumer: FDCG (function of market depth)

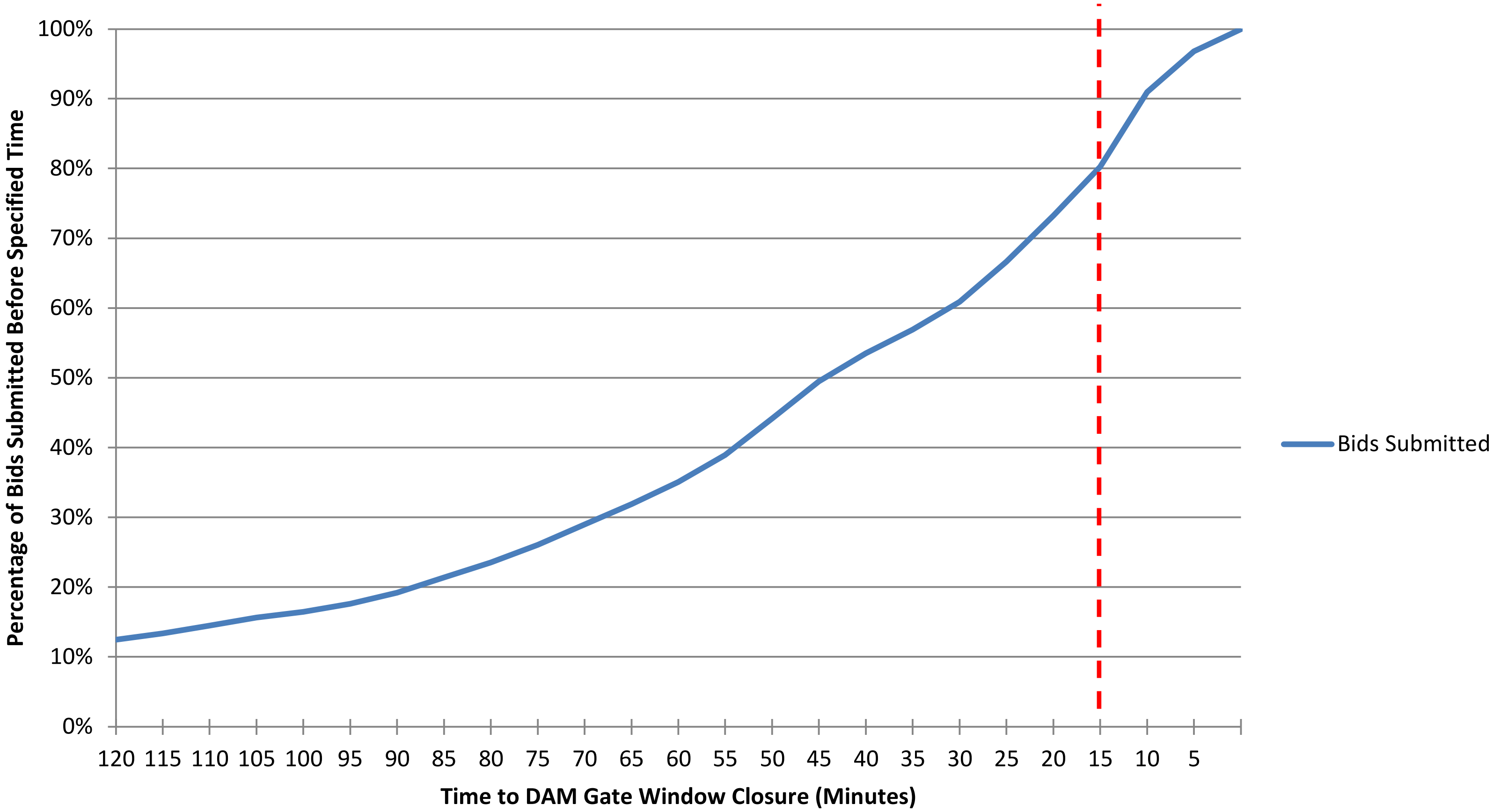
- Isolated market price, S increases to U
- Consumer surplus: decreases by SRWU
- Producer surplus: increases by USRV
- Overall surplus: increases by RWV
- Transfer consumer to producer: USRW (function of market depth)

Preliminary Order Books

- Using preliminary order books in means MRLVC allocation is based on the wrong order books, not reflecting orders received in SDAC after the preliminary gate closure
  - Impacts the isolated BBZ clearing price
  - Impacts the BBZ market depth/price resilience and consequently the relationship between the BBZ price and the IC flows
- Using non-firm market orders exposes MRLVC to market manipulation/strategic bidding
  - Example: generators in BBZ A wishing to raise the DAM price in A could deliberately induce exports on the IC to GB – where perfect coupling would indicate imports – by bidding large sell volumes at low prices at the preliminary gate closure, subsequently modifying their orders before the final GCT
  - Smaller BZs with low price resilience are particularly vulnerable
  - Such behaviour would be almost impossible to police effectively (the incentive to bid strategically would be widespread and hard to prove)
- Implications are highly inefficient flows, erroneous price signals, disorderly energy markets, loss of social welfare and severe impairment of transmission revenue

Order book submission

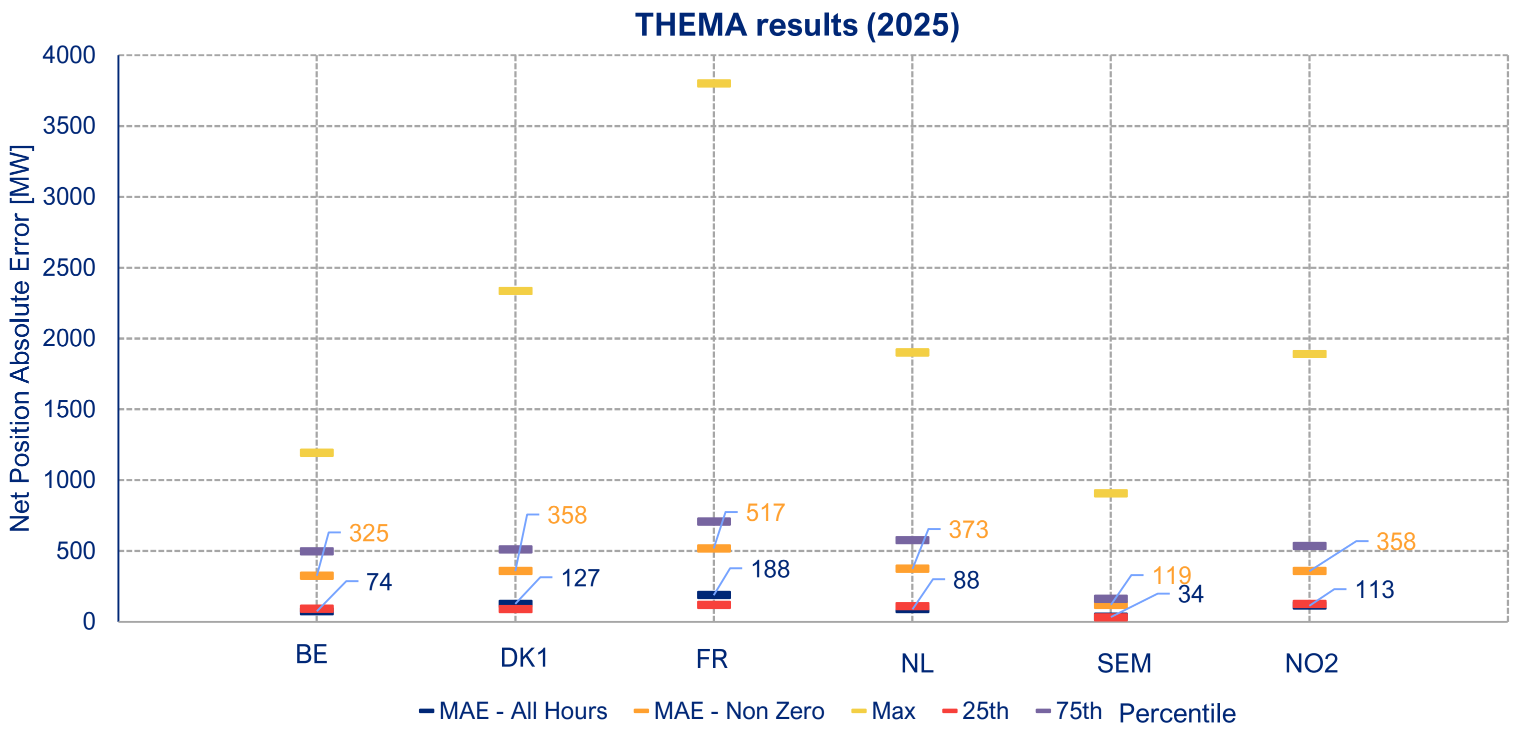
SEM DAM bid submission time by Unit relative to Gate Closure



Values are based on the number of orders for each unit submitted, not the MWh volume of trades

Impact of BBZ flow forecast error

- In the LVC simulations for 2025, not all forecasting errors from the perturbations outside the BBZs lead to high errors in the modelled flows with GB.
- The number of instances in which the flow on each border was disturbed ranges between 1000 and 2500 hours, with FR, DK1, and NO2 lying in the higher end.
- The absolute error against the optimal flow for the different lines to the BBZs are summarized below.

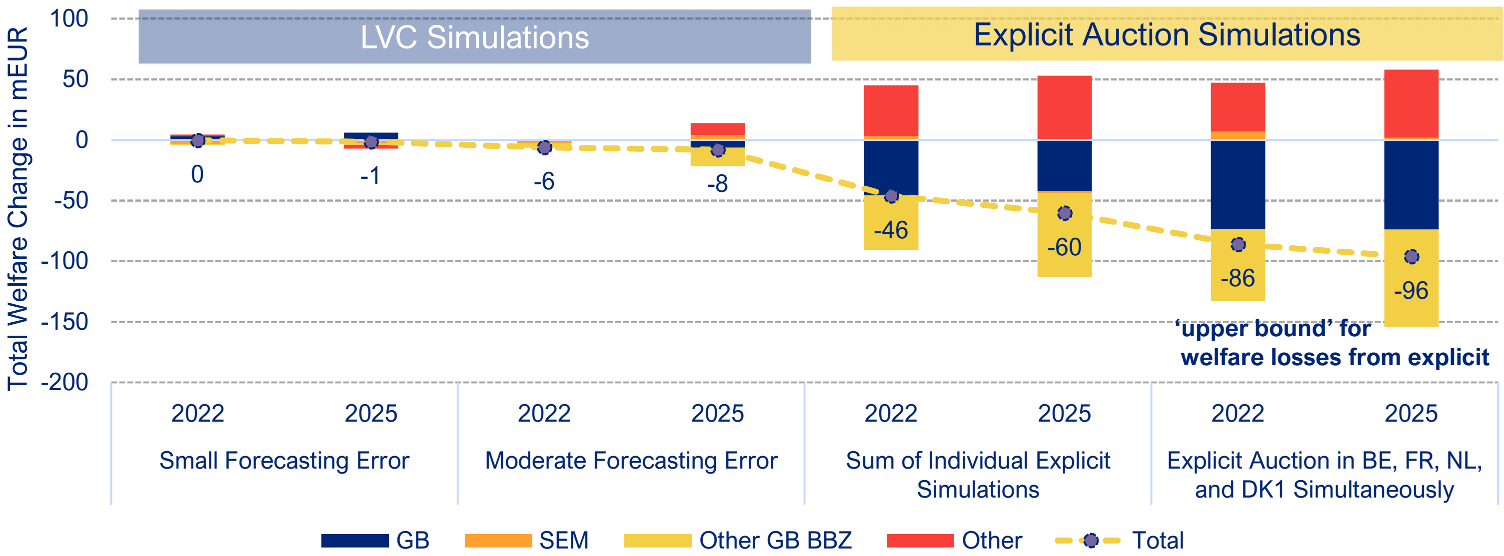


MAE - All Hours : Mean absolute error in all hours
MAE – Non Zero: Mean absolute error on hours with non-zero errors
25th and 75th percentile are calculated for hours with non-zero errors.

Overall welfare impacts

- Results from both modelling tools are in line with qualitative expectations
  - Poorer quality BBZ forecast leads to moderate reduction in welfare (see Small Forecasting Error v Moderate Forecasting error)
  - In Explicit, nominating flows based on DA price differentials from efficient flows can lead to more frequent sub-optimal IC flows (i.e. under-utilisation of IC capacity)
  - Welfare losses under explicit and under MRLVC (imperfect forecasts) increase over time, as efficient flows become more important with increased RES penetration

THEMA results: Total welfare loss under LVC Simulations and Explicit Auction simulations

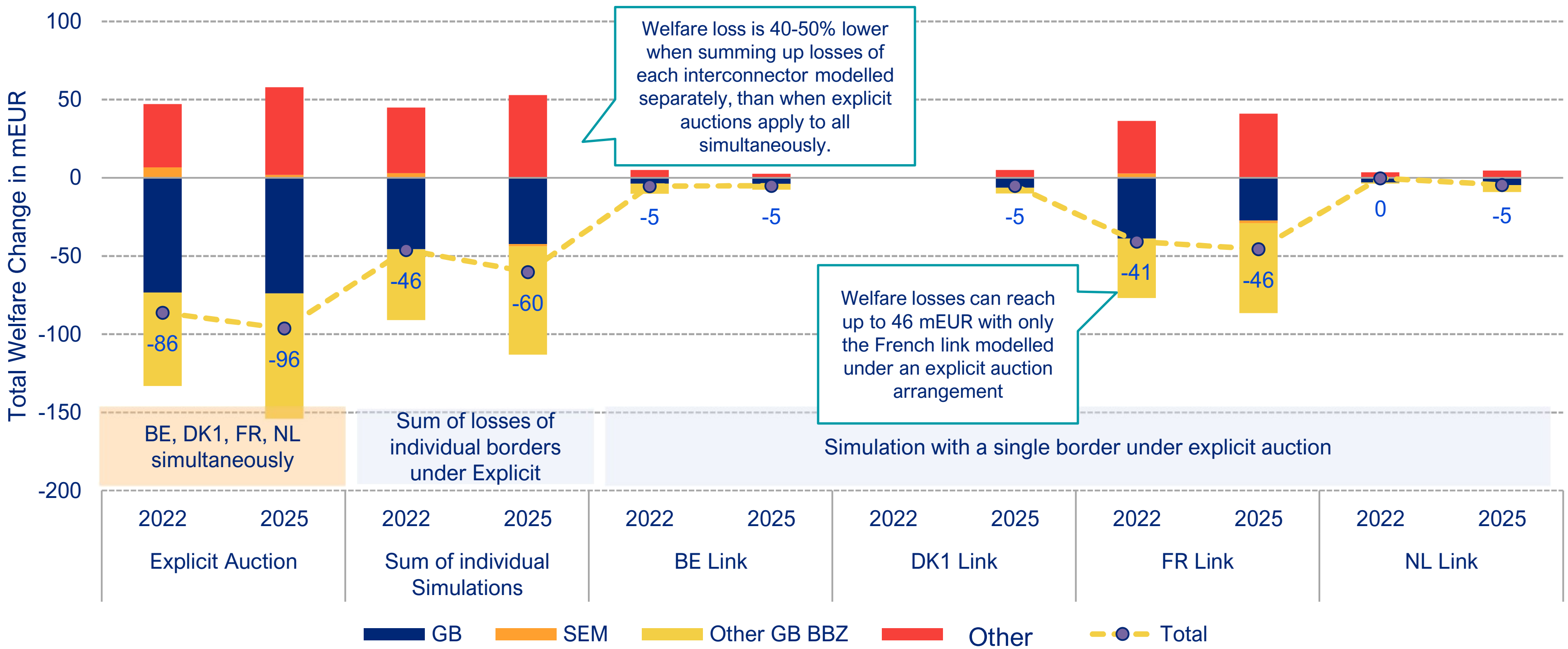


**"Other" refers to the rest of the modelling are including Austria, Italy, Spain, Portugal, Poland, Switzerland, Czech Republic, Germany, the Baltics, Finland, Denmark, Sweden.*

Testing of single explicit auction

- We have tested the effect of explicit auctions on each border. This is to test additivity and to determine which links have most impact.
- The results show that the total possible welfare losses can be much higher when explicit auctions apply **simultaneously** on all 4 borders than when summing the losses of each border modelled **separately** under explicit auctions.

THEMA results: Total welfare loss under explicit auction simulations – simultaneously and per border

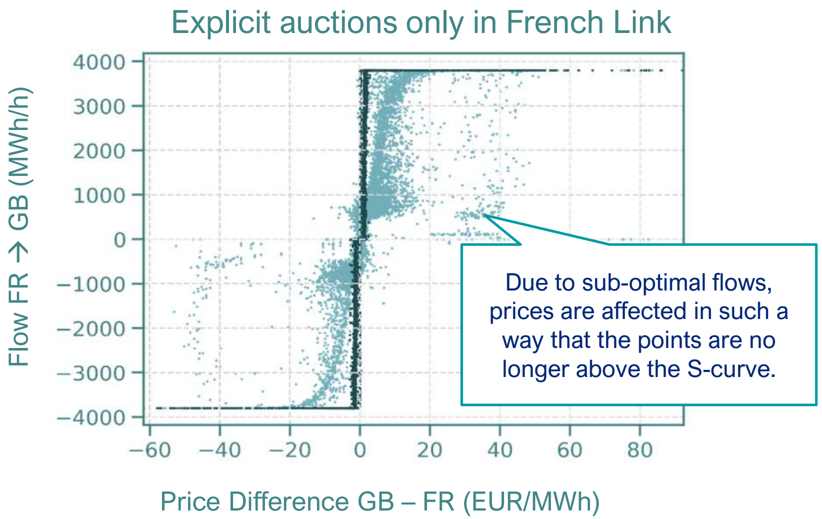


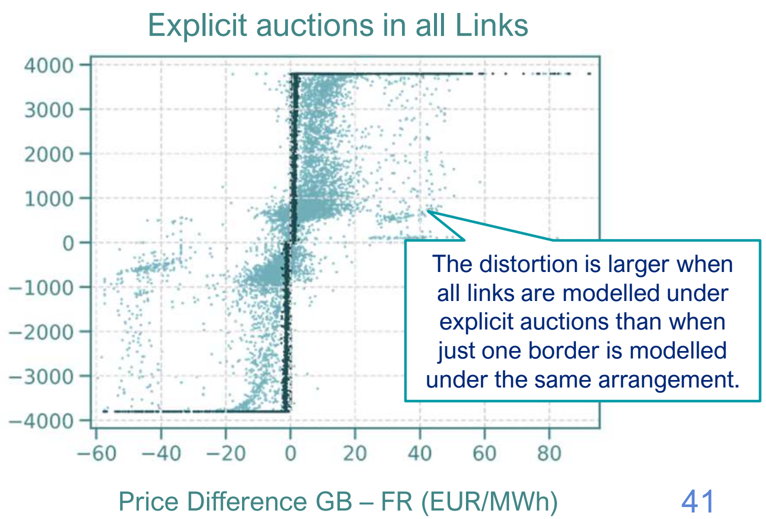
**"Other" refers to the rest of the modelling are including Austria, Italy, Spain, Portugal, Poland, Switzerland, Czech Republic, Germany, the Baltics, Finland, Denmark, Sweden.*

Challenges of modelling explicit

The estimated welfare losses under explicit should be taken as an upper bound due to the uncertainties around formation of price expectations

- Fixing the nominated flows influences the price spreads, with no feedback to flow nominations, which causes some points to lie outside the S-curve (from our analysis for the DE-CH border).
- From additional testing, the modelling of explicit auctions on single borders does not yield worse performance than the historical performance seen on the DE-CH border.
- However, when THEMA models explicit auctions simultaneously (in our counterfactual), the price distortion is higher. This causes some links to perform worse than the historical performance seen on the DE-CH border. This can overestimate the negative welfare effect; and hence the results for simultaneous explicit auctions can be seen as an upper bound for losses.
- The result is also a good example of the circularity challenge traders face when nominating capacities, as they must guess the future price spreads to nominate a flow, with the nomination subsequently affecting price spreads.

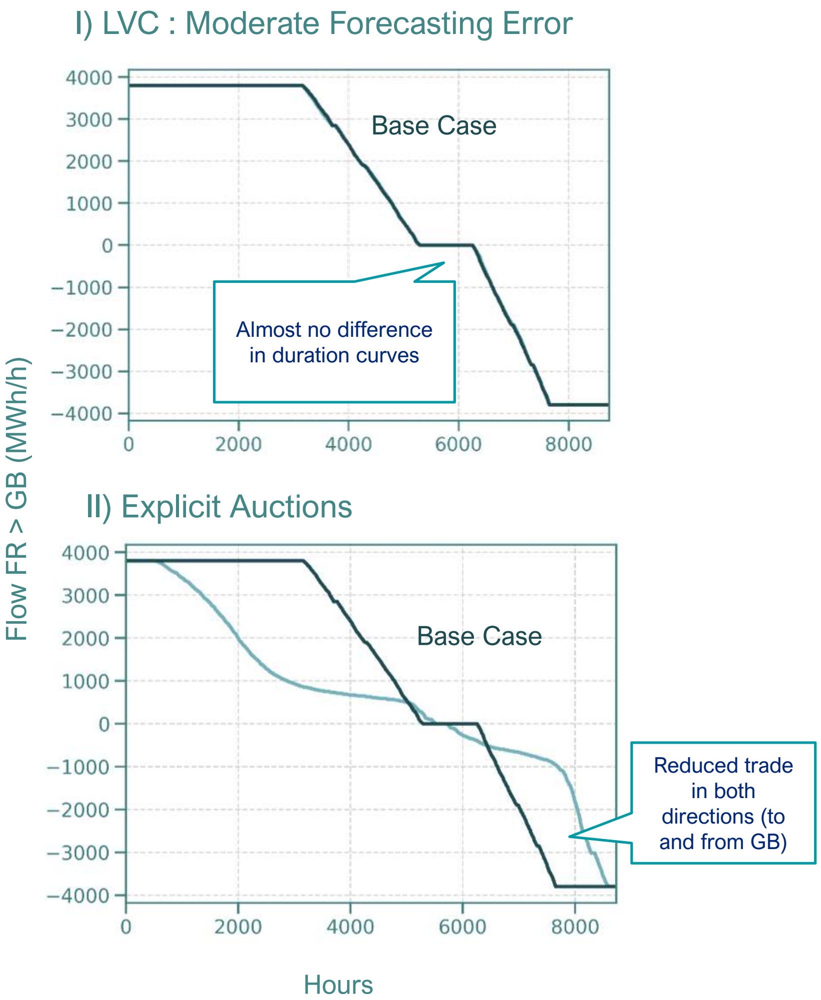




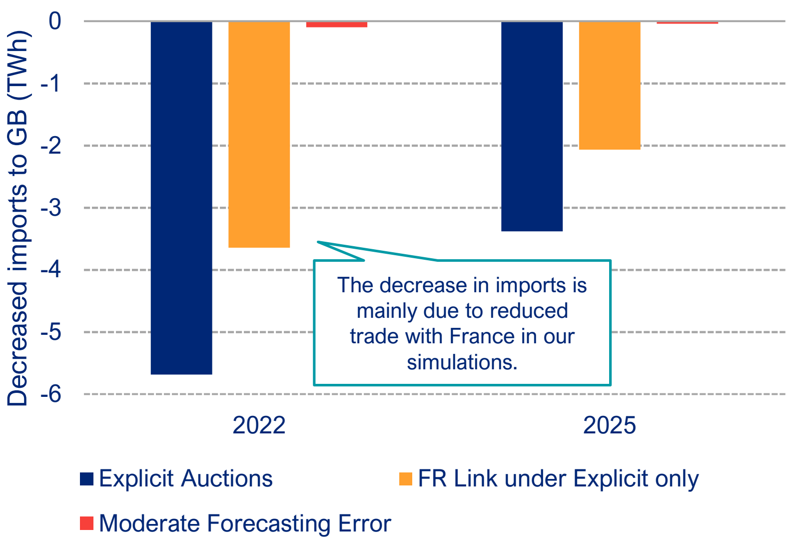
Inefficient trade across IC

Net Flow Duration Curves between FR and GB

THEMA results



- **With LVC, capacity is typically fully utilized but with occasional flows in the wrong direction.**
- **With explicit auctions, reduced trade is the main source of welfare loss.**
  In addition, flows against a price differential can occur, increasing overall inefficiencies. As discussed earlier, we see this as an upper bound for welfare loss because of the impact of simultaneous explicit auctions.
- Reduced GB imports due to inefficient trade has consequences for CO2 emissions, prices, and welfare, particularly under explicit auctions



Interconnector revenues

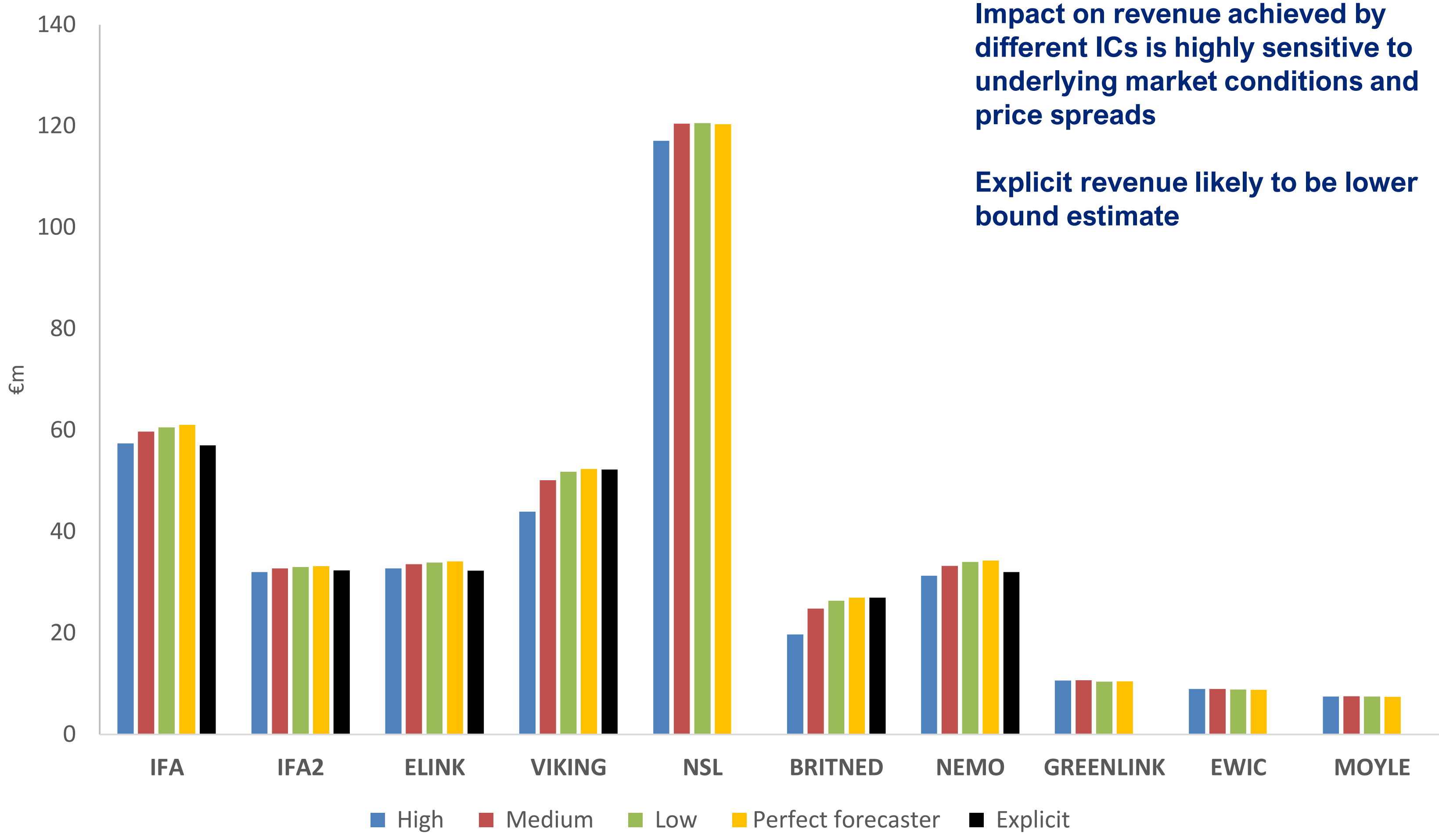
Common Order Books	Preliminary Order Books	Explicit Auctions	Intraday Price Coupling	Separate Day Ahead Coupling
× Loose volume coupling leads to: • adverse and below optimal flows (FAPDs) • UIOSI payout greater than congestion revenue × Non uniform impacts: some ICs may benefit from FAPDs on others × Intraday allocation of any underused capacity typically priced lower than DA	× Increased risk of inefficient flows and FAPDs compared to Common Order Books due to incomplete order books and potential manipulation × Intraday allocation of any underused capacity typically priced lower than DA	✓ Good valuation while price spreads are consistently one way × Capacity values poor, especially in non-prevailing direction, when spreads are switching direction (significant when prices levels are close) × Intraday allocation of any unused capacity usually priced very low	× Substantial reduction in price spreads compared to between DAMs (reduced market interest after DA trading)	✓ Efficient flows, provided DAMs are accurate (uncertain due to fragmented GB and NO2 DAMs) ? Pricing efficiency depends on how close the DAM prices are to SDAC/NO2 and other GB DAMs ✓ Additional price volatility increases congestion revenue

Possible mitigations:

- Tighter coupling – e.g. better quality BBZ flow forecasts
- Avoid any subjective or non-transparent basis for forecasting BBZ flows
- Treat MRLVC-calculated flows as limit orders on SDAC

TSO Interconnector Revenue (I)

Annualised Revenue, SDAC SF modelling

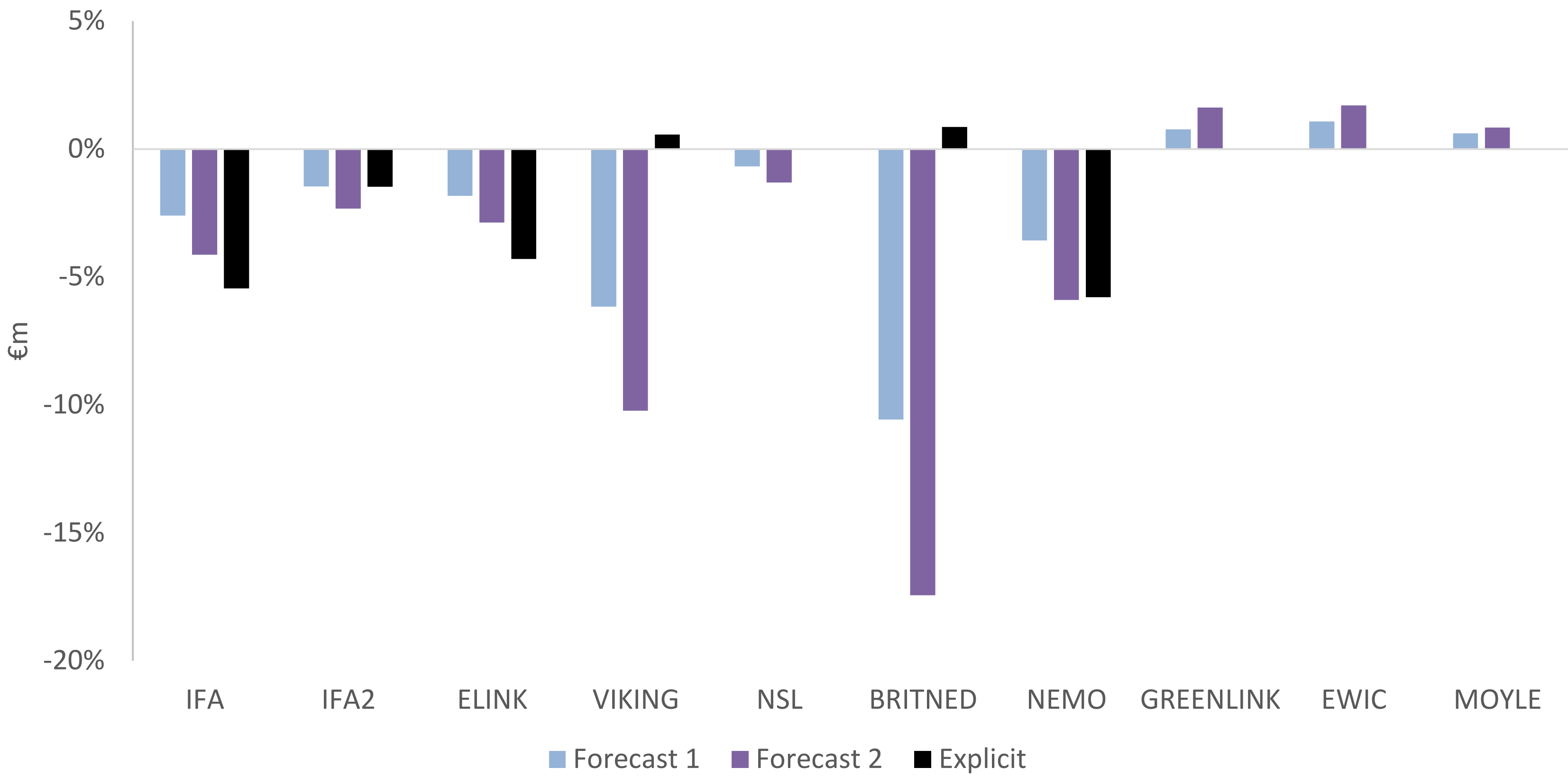


Impact on revenue achieved by different ICs is highly sensitive to underlying market conditions and price spreads

Explicit revenue likely to be lower bound estimate

TSO Interconnector Revenue (II)

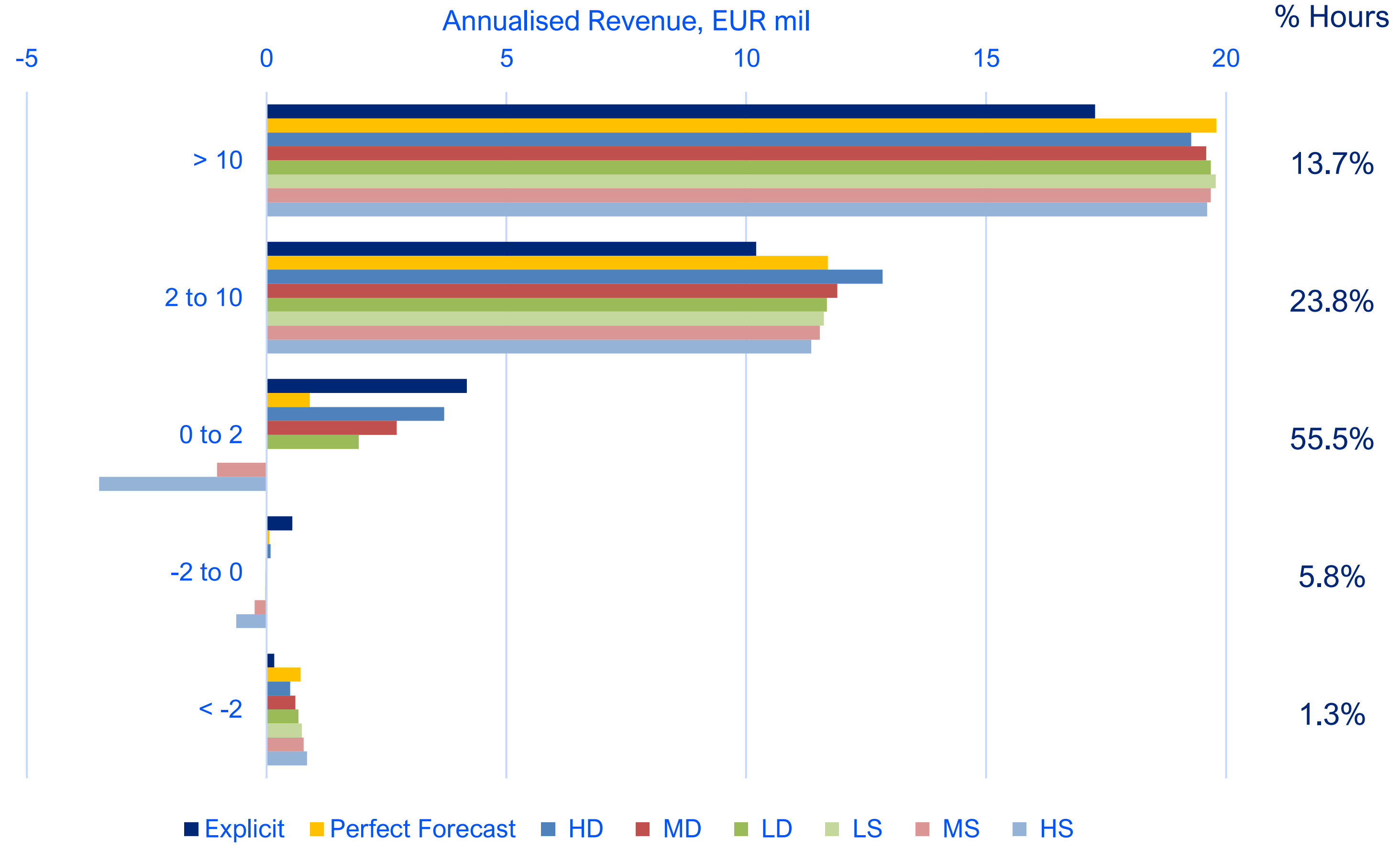
% change vs Perfect Forecaster, SDAC SF modelling



Forecast 1: average of all scenarios (High, Medium and Low perturbation; perfect forecaster)
Forecast 2: average of High and Medium perturbation scenarios

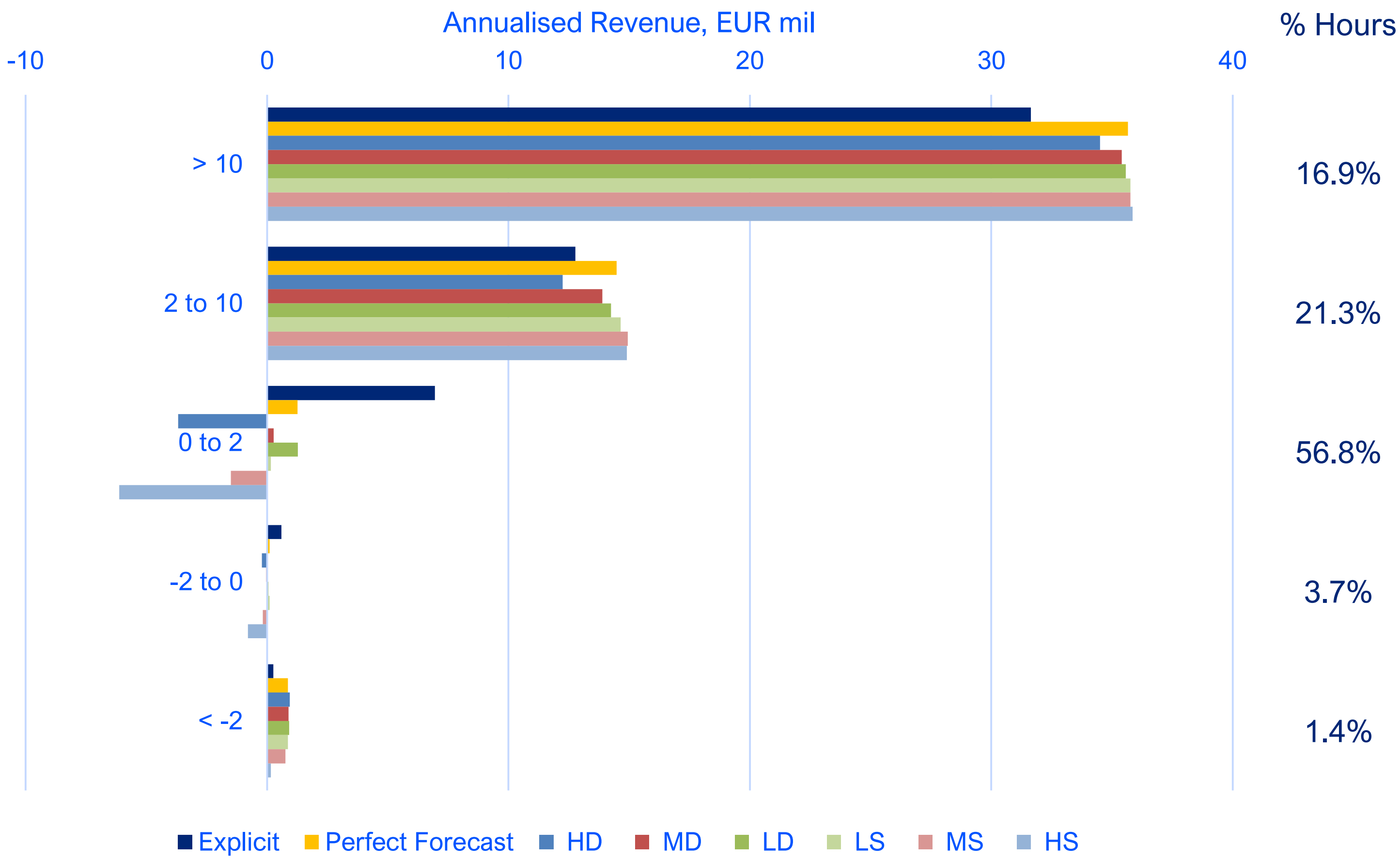
TSO Interconnector Revenue (III)

IFA2, by LAPD range (€/MWh), SDAC SF modelling



TSO Interconnector Revenue (IV)

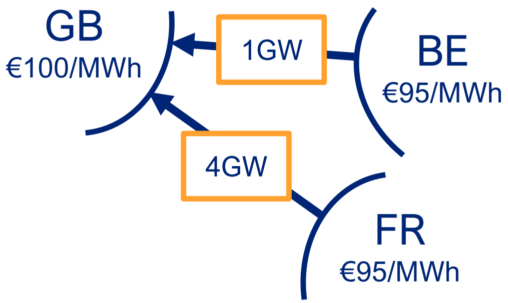
Viking, by LAPD range (€/MWh), SDAC SF modelling



Different impact of looseness

Illustrative example

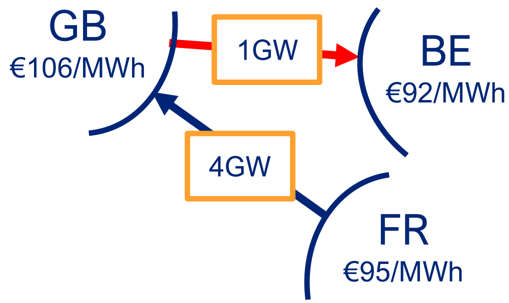
Perfect Coupling



Congestion revenue

BE-GB:	€5,000
FR-GB:	€20,000
Total	€25,000

High Demand perturbation



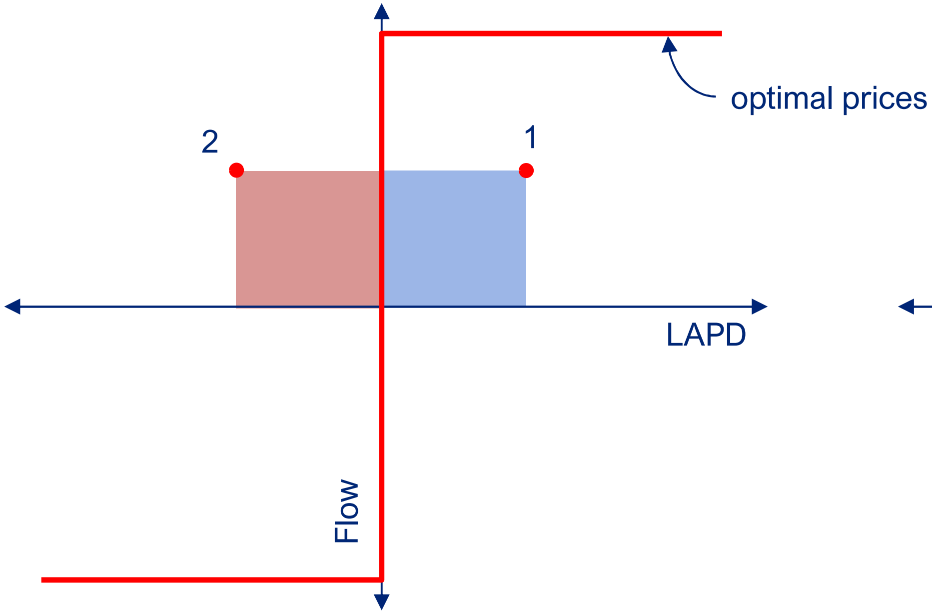
Congestion revenue

BE-GB:	€-14,000
FR-GB:	€44,000
Total	€30,000

- FAPDs caused by loose coupling result in negative congestion revenue on that link (here BE-GB)
- Impact may, however, be positive on links that are scheduled correctly (here FR-GB)
- Overall impact can be increased congestion revenue compared to perfect coupling
- Scenario observed in historic simulation; other effects possible depending on market conditions

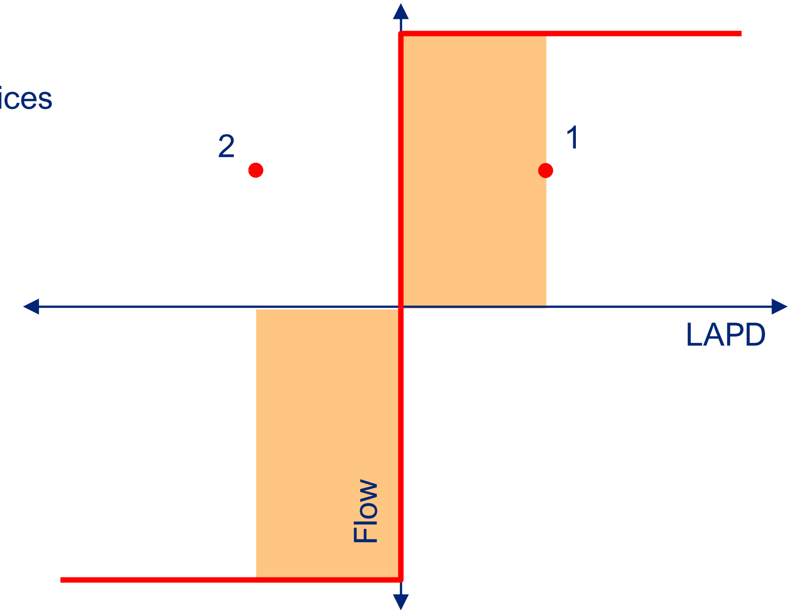
Impact of price discrepancies

Congestion Revenue



1. LAPD>0; uncongested
   - Positive congestion revenue
   - Revenue reduced by transmission losses
2. LAPD<0; uncongested
   - Negative congestion revenue
   - Loss increased by transmission losses (asymmetric with case 1)

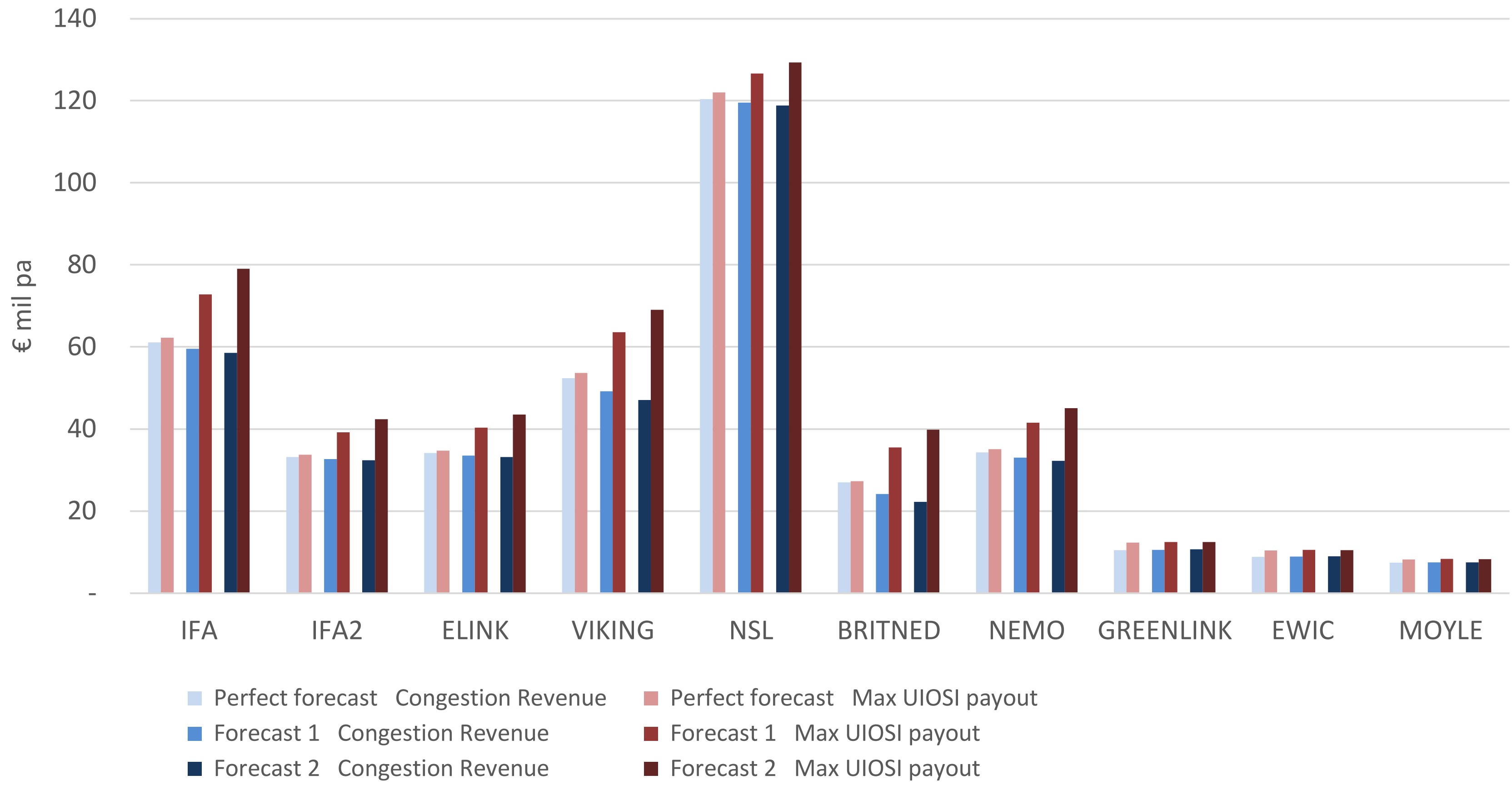
UIOSI Payout



1. LAPD>0; uncongested
   - Payout only partially covered by congestion revenue (full ATC)
   - Payout reduced by transmission losses
2. LAPD<0; uncongested
   - Uncovered payout
   - Payout reduced by transmission losses

UIOSI/FTR Payout

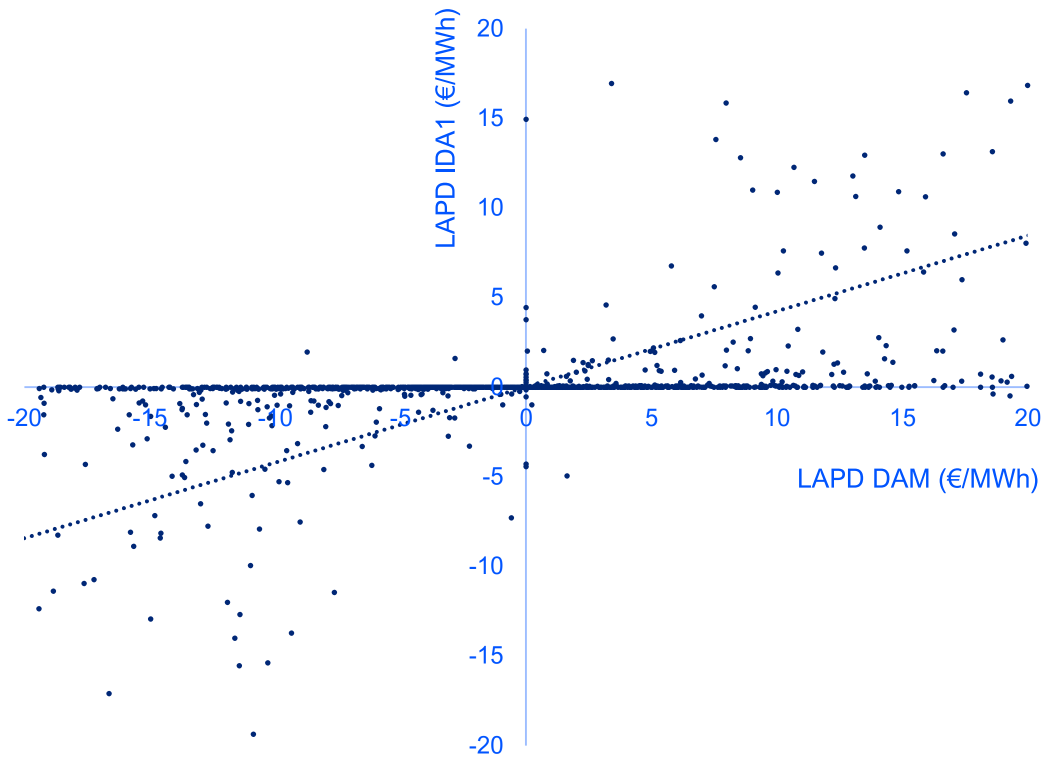
SDAC SF modelling (1/7/2019-30/6/2020)



UIOSI Payout assumes max of NTC and DA ATC is offered in either direction as FTR or LTR with UIOSI
Forecast 1: average of all scenarios (High, Medium and Low perturbation; perfect coupling)
Forecast 2: average of High and Medium perturbation scenarios

SEM-GB: ID Implicit Auction

ID vs DA LAPD for SEM-GB, actual 2021



Loss adjusted price differences (and consequently congestion revenue) significantly smaller in 17:30 ID implicit auction compared to DAM spreads (SEM DAM vs weighted average of GB DAMs)

- 60% less than average DAM LAPD*
- Some price variation to be expected since different market time – but should be unbiased

Significant periods with zero ID LAPD (i.e., uncongested interconnection) even when DAM LAPD was large: implies a loss of potential economic surplus from trading

*Divergence can partly be attributed to SEM DAM being isolated whilst SEM IDA is coupled; to the extent that SEM market participants cannot freely arbitrage between the two markets.

NSL: Impact of DAM volatility

Simulated Congestion Revenue (€/MW/h), NSL SDAC SF modelling (1/7/2019-30/6/2020)

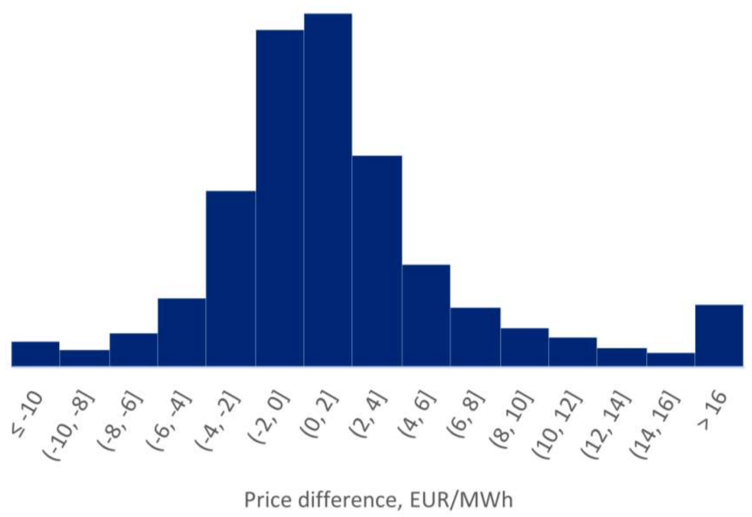
- Introducing variation in the GB and NO2 prices (compared to GB DAM and NO2 SDAC) tends to increase congestion revenue
- Assumes price variations to both GB and NO2 DAM are independent, unbiased, normally distributed (standard deviation of 5/10 EUR/MWh in moderate/severe scenario)

Fragmented DAMs

Price variations

Germany

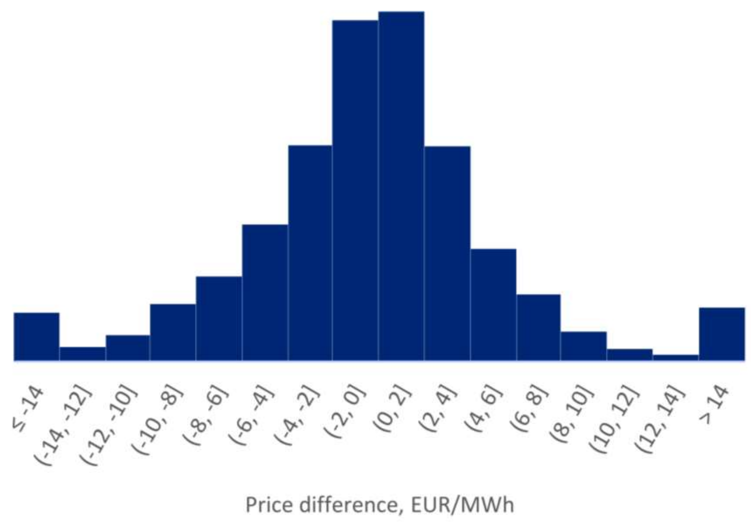
EXAA vs EPEX, 2017-20



- EXAA first at 10:15 CET; EPEX (larger market) at 12:00
- 1st quartile: -1.53 €/MWh
- Median: 0.60 €/MWh
- 3rd quartile: 3.28 €/MWh
- St deviation:

Great Britain

EPEX vs N2EX, Q1 2021



- EPEX first at 09:20 (UK); N2EX (larger market) at 09:50
- 1st quartile: -3.14 €/MWh
- Median: -0.05 €/MWh
- 3rd quartile: 2.43 €/MWh

CO2 and low carbon targets

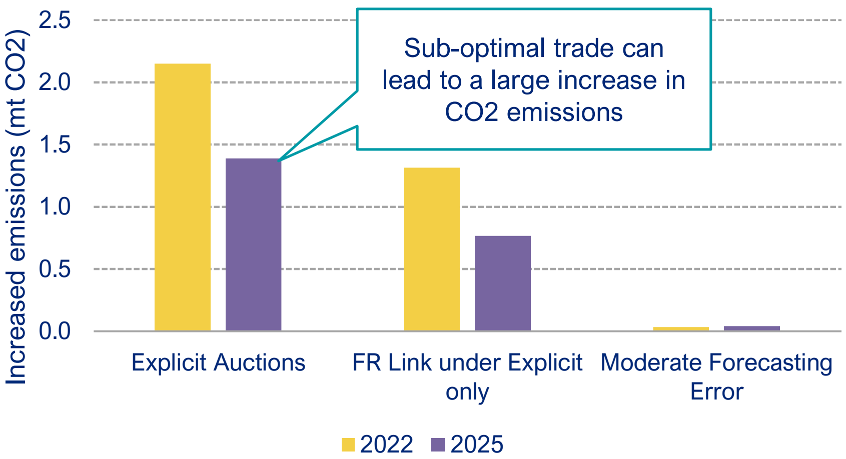
Common Order Books	Preliminary Order Books	Explicit Auctions	Intraday Price Coupling	Separate Day Ahead Coupling
✓ Impact on RES despatch limited given low marginal cost and ID trading opportunities × A poor solution creates risk of significant underutilisation of capacity and/or FAPDs on hybrid ICs/North Sea grid – likely barrier to investment	✓ Impact on RES despatch limited given low marginal cost and ID trading opportunities × A poor solution creates risk of significant underutilisation of capacity and/or FAPDs on hybrid ICs/North Sea grid – likely barrier to investment × Increased risk compared to Common Order Books due to incomplete order books and potential manipulation	× Reduced trade can increase need for fossil fuel generation in GB, and/or curtail RES unable to export, unless mitigated by ID × Risk of significant underutilisation of capacity and/or FAPDs on hybrid ICs/North Sea grid – likely to barrier to investment × Uncertain capacity availability	✓ Able to facilitate efficient despatch of RES × Poor congestion revenue performance likely to undermine hybrid interconnector investment (but less relevant to SEM-GB)	✓ Able to facilitate efficient despatch of RES × Incompatible with an interlinked North Sea grid also using SDAC

Possible mitigations:

- Tighter coupling – e.g. better quality BBZ flow forecasts
- Enhanced representation and data availability in MRLVC of any North Sea grid/BZs

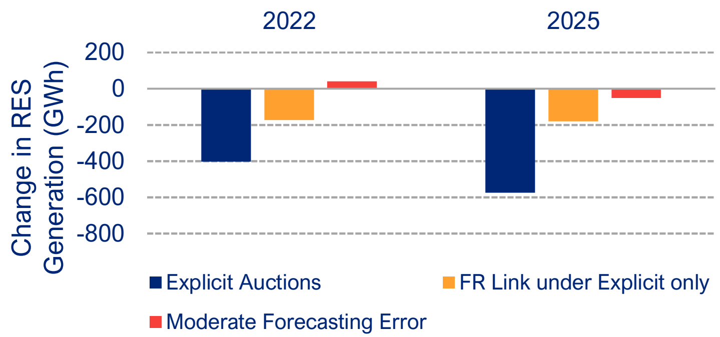
CO2 emissions

- Decreased trade opportunities lead to higher need for fossil fuel generation in GB, mostly gas generation towards 2025.
- Increase in emissions in GB is mostly driven by inefficient trade with France in the explicit auction scenario. As discussed earlier, we see this as an upper bound for emissions increase because of the impact of simultaneous explicit auctions.
- Emission increase under the small and moderate errors, are very limited.

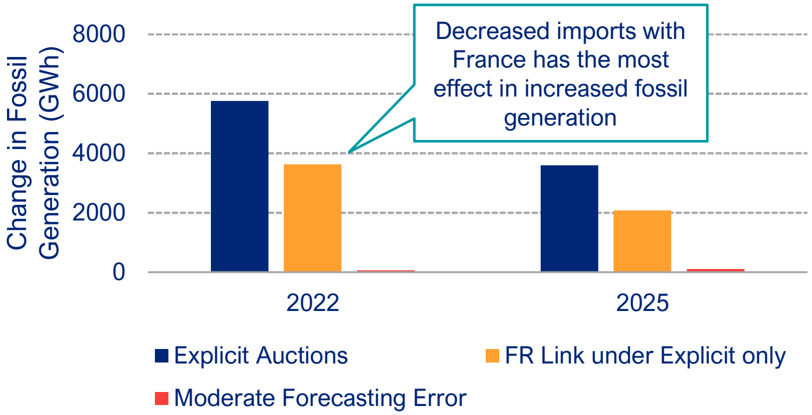


Source: THEMA model

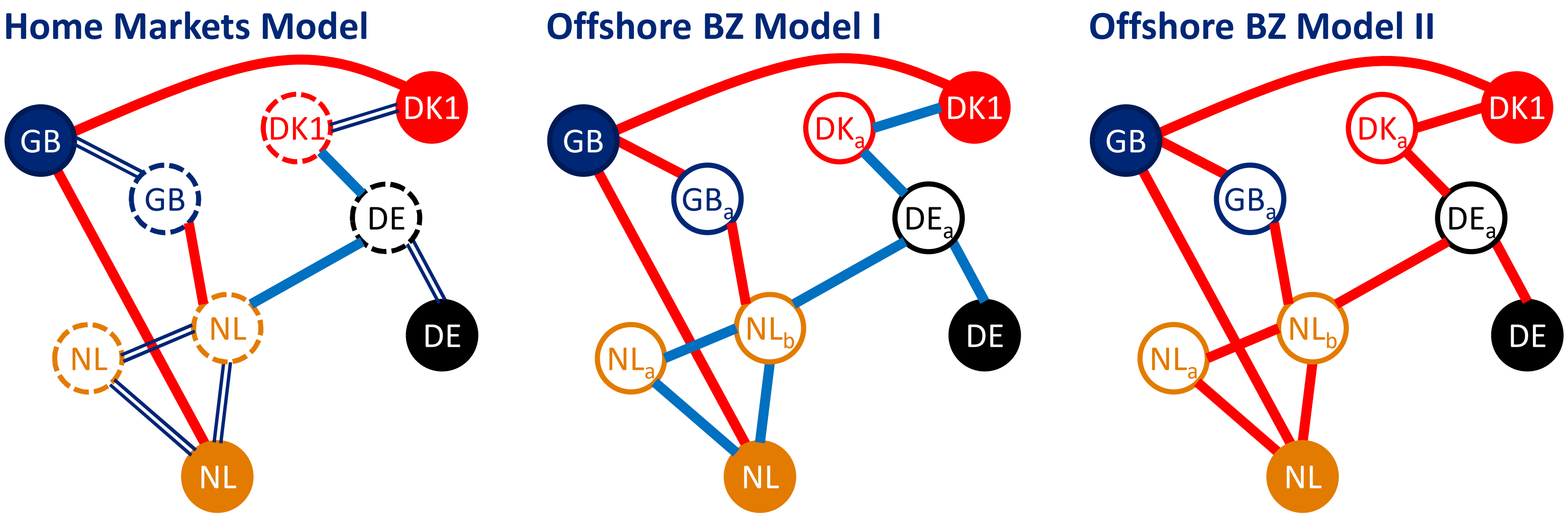
- Locked-in generation also contributes to the increase in fossil generation, as RES generation (particularly wind) must be curtailed in some hours.



- Together with decreased imports, fossil generation increases in GB.

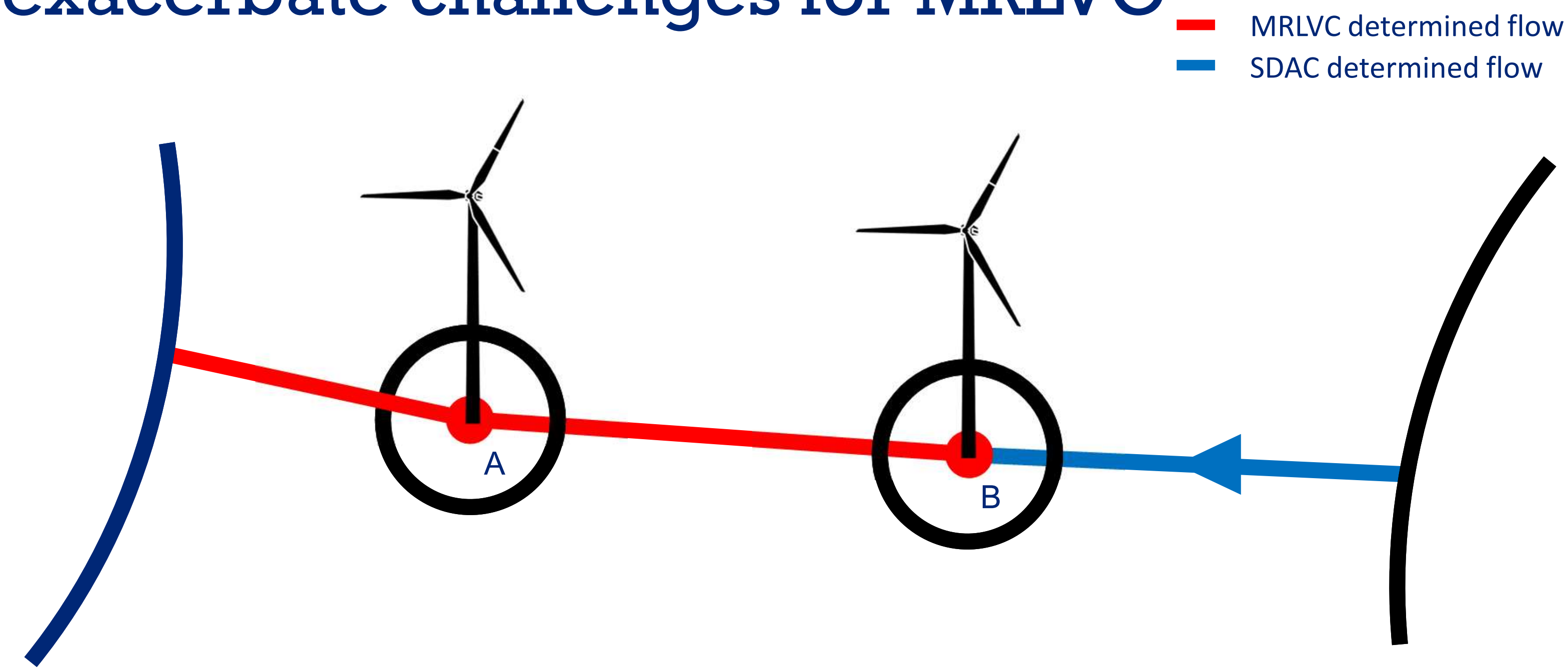


Potential implications of offshore bidding zones



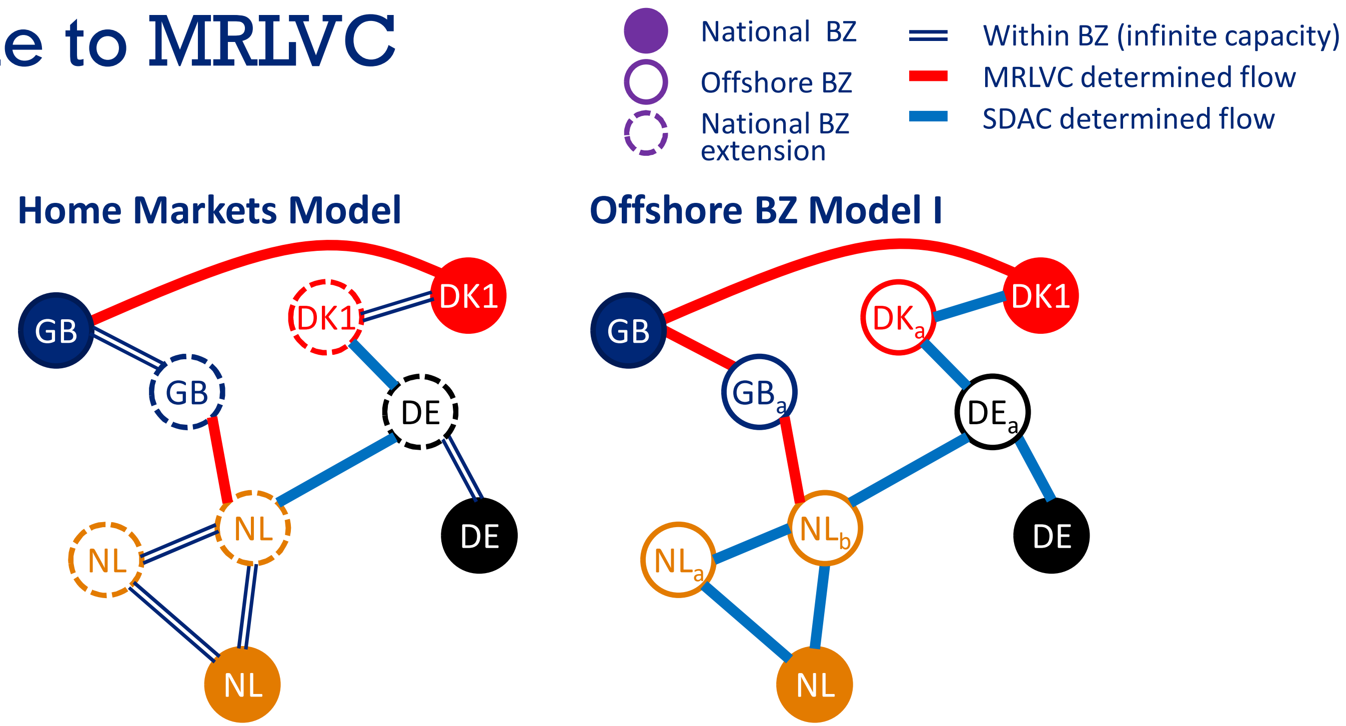
- Proposed development of North Sea consistent with climate targets envisages creation of hundreds of GWs of offshore wind capacity, much of it linked to multiple shores through so-called hybrid projects (hybrid interconnection and generation).
- The EU's offshore renewable energy strategy has raised the possibility of creating offshore bidding zones to account for structural bottlenecks in the offshore grid (shown with subscripts above).
- Key issue in the development of a commercial/regulatory framework for a North Sea hub is how MRLVC plus SDAC will enable accurate price signals, optimal capacity allocation and incentives for efficient investment

These system changes may exacerbate challenges for MRLVC



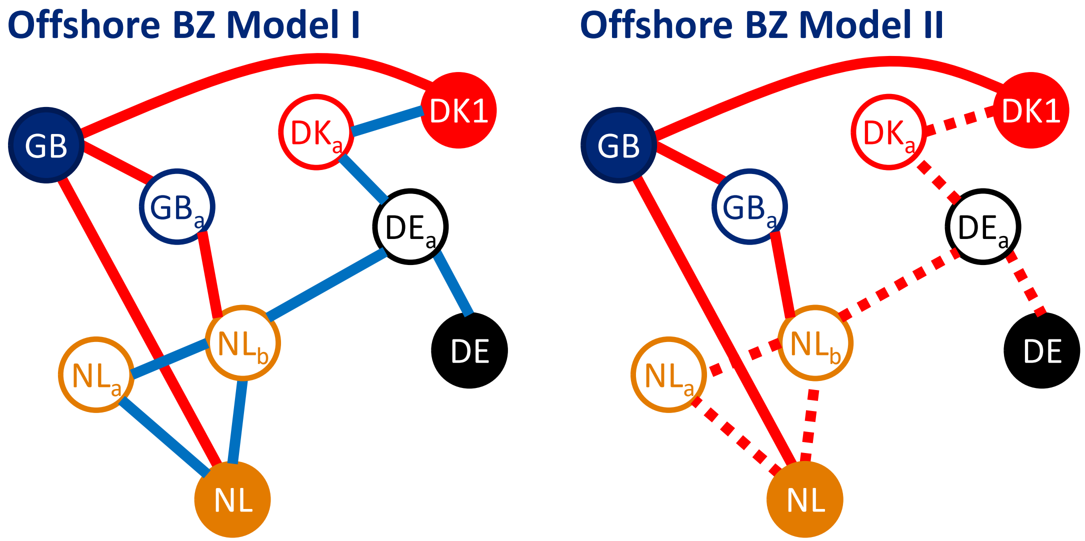
- Use of Offshore Bidding Zones gives the market coupling process a greater role in undertaking the challenging job of optimising flows within the offshore network.
- The optimal cross-zonal flow for borders within the offshore network is likely to be far more sensitive to flows on adjacent borders because these cross-zonal flows will represent a very large share of total implied demand/supply in the relevant offshore zone as compared to existing onshore zones.
- Optimal flows may also be more sensitive to generation in other bidding zones given the offshore topology. For example, SDAC-determined flows as shown above may be limited by assumed generation in bidding zone A. This greater sensitivity increases the risk of inaccurate/inconsistent assumptions resulting in sub-optimal flows.

OBZs may act to limit info available to MRLVC



- In the example above, the introduction of Offshore Bidding Zones effectively hides information on bids/offers the NL onshore zone from the MRLVC process, as the offshore bidding zone, NL_b, becomes the neighbouring zone.
- In effect, information on Dutch onshore bids/offers is replaced with TSO forecasts of flows to/from NL_b. Depending on the quality of these forecasts, this has the potential to:
  - Result in inefficient/adverse flows
  - Affect prices, notably in the offshore zones
- Note that while this might be superficially seen as an argument against offshore bidding zones, the home markets model is really just hiding the network constraints from the market and is still going to imply the need for the TSOs to manage constraints between the offshore hubs.

Information impacts of OBZs may be limited

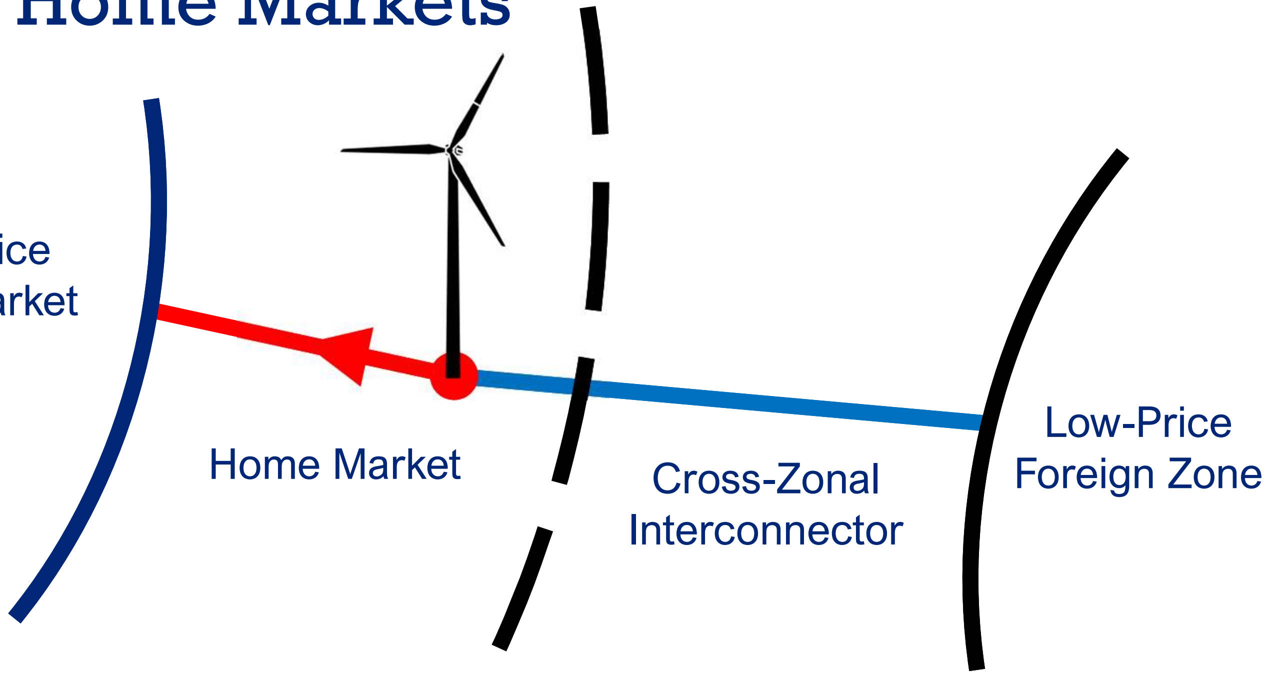


- The effect of the creation of offshore bidding zones on the data used as part of MRLVC will depend on the extent to which offshore bidding zones replace shore-to-shore borders. In the example shown on the left, the GB and NL onshore zones continue to share a border (through a traditional shore-to-shore interconnector) despite the creation of offshore bidding zones. In this case, there is no reduction in the information available to MRLVC.
- Another, more general, possibility to mitigate the impact of offshore bidding zones on visibility is to provide the MRLVC process with bid/offer data for more remote zones even where they do not share a direct border with a GB bidding zone.

Explicit auctions face major challenges

- Explicit auctioning of transmission capacity remains technically feasible under both the home markets and offshore bidding zone models.
- However, the greater difficulty associated with correctly anticipating optimal flows, for example due to the uncertain volume of offshore generation, leads to a greater risk of underutilisation and adverse flows under explicit auctions (where rights owners must each make their own determination of the correct flow).
- By reducing the number of borders, the home markets model makes the forecasting of flows on the borders that remain easier for rights owners and likely reduces these issues.
- However, it also implies that cross-zonal capacity available on the border becomes hard to anticipate.

Challenge of identifying CZC under Home Markets



- In the example above, import capacity into the Home Market will likely be a function of offshore generation and therefore hard to predict.
- To deal with this problem under a explicit auction model, the transmission owner may be forced to:
  - Factor in a safety margin and effectively undersell capacity (underutilisation)
  - Only sell capacity very close to real to real time
  - Sell capacity that isn't firm (nominations can be changed)
  - Impose countertrade costs (on the TSO)

Key impacts from offshore developments

- Developments in the North Sea do not lead to fundamentally new problems but may exacerbate existing challenges. The risk is that we see adverse or inefficient flows on the relevant borders.
- Inefficient trade results in a direct welfare loss. Further losses due to dispatch efficiency will probably be limited for low-marginal cost offshore wind, since this will almost always be in-merit. However, losses could result if, for example, hydrogen production is located in offshore zones.
- Inefficient flows would harm the commercial investment case for (hybrid) transmission infrastructure and thereby harm the commercial investment case for offshore hybrid renewable projects. The carbon impacts of this will depend on to what extent deployment is driven by commercial rather than policy incentives.

Meeting market needs

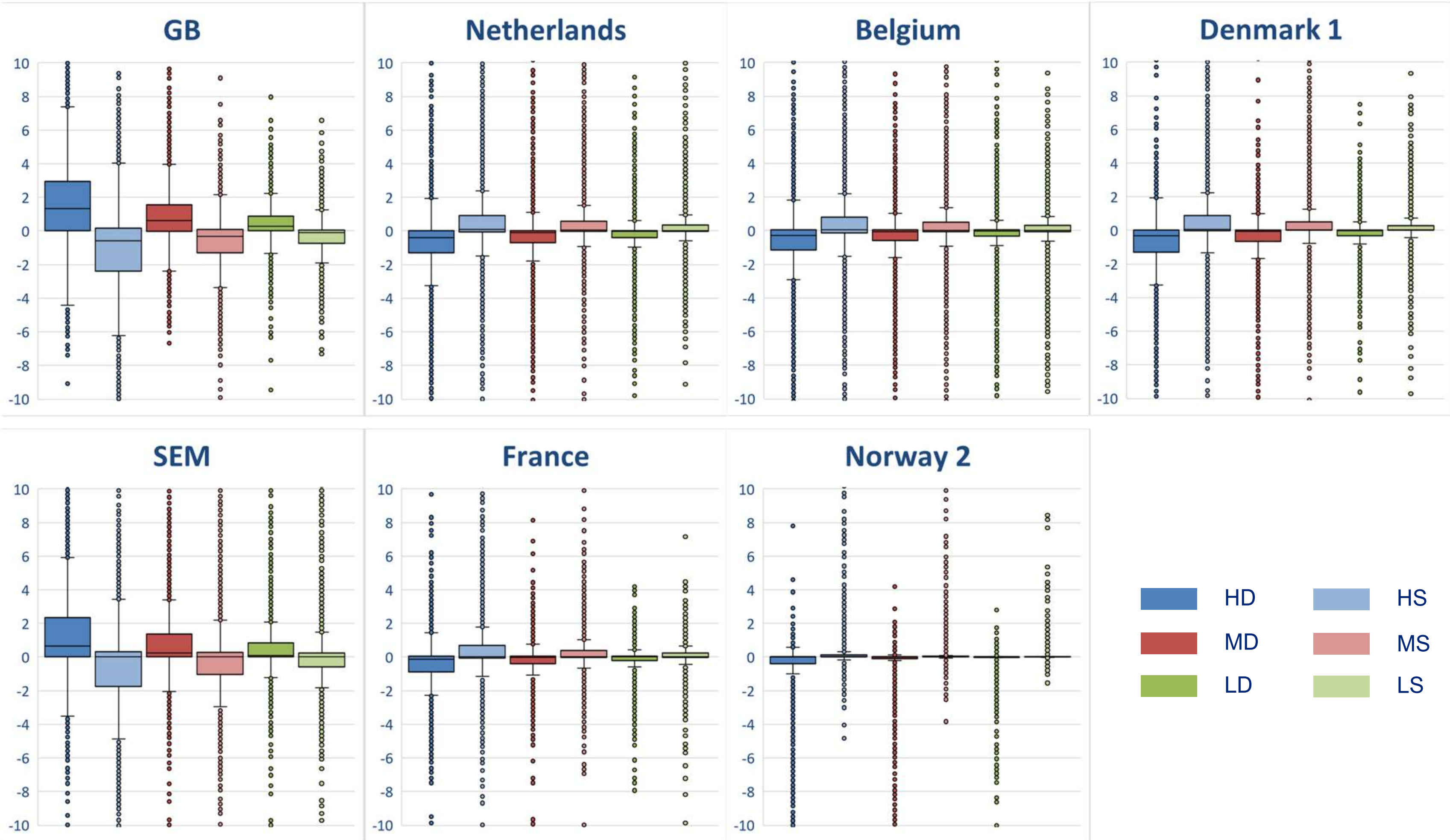
Common Order Books	Preliminary Order Books	Explicit Auctions	Intraday Price Coupling	Separate Day Ahead Coupling
× Loose volume coupling leads to DAM price distortions × Any subjective forecasts of BBZ flows harm market confidence ✓ Unified GB DAM markets • concentrate liquidity to support complex products • reference price • supports choice of DAM platform × Lengthens market process by possibly 10-15 minutes in SDAC	× Increased risk of price distortions compared to Common Order Books due to incomplete order books and potential manipulation × Any subjective forecasts of BBZ flows harm market confidence ✓ Unified GB DAM markets (as for Common Order Books)	× Weakened price formation in DAMs × Operationally complex for market participants (multiple auctions; pricing uncertainty): barriers to participation ✓ No impact on SDAC timing; GB DAMs can be very quick	× Uncertain IC flows at time of SEM DAM: added uncertainty to price formation × Limited participation in IDA – parties seek a position earlier in the day ✓ Unified GB IDM markets, but less critical than for DAM (no reference prices)	× Fragmented GB and NO2 DAM markets: • suboptimal liquidity to support complex products in GB • no single reference price × Initially only planned to be accessible via one PX (may change) ✓ No impact on SDAC timing; GB-NO coupling can be quick

Possible mitigations:

- Tighter coupling – e.g. better quality BBZ flow forecasts
- Avoid any subjective or non-transparent basis for forecasting BBZ flows

Impact on DAM Prices

Scenario prices vs Perfect Forecast, €/MWh, SDAC SF modelling (1/7/2019-30/6/20)



IC technical compatibility

Common Order Books	Preliminary Order Books	Explicit Auctions	Intraday Price Coupling	Separate Day Ahead Coupling
✓ Supports losses ✓ Supports period-to-period ramping ? Minimum stable flow, overload optimisation (not critical)	✓ Supports losses ✓ Supports period-to-period ramping ? Minimum stable flow, overload optimisation (not critical)	✓ Supports losses × Does not support period-to-period ramping (may be critical for some future ICs) ? Minimum stable flow, overload optimisation (not critical)	✓ Supports losses ✓ Supports period-to-period ramping ? Minimum stable flow, overload optimisation (not critical)	✓ Supports losses ✓ Supports period-to-period ramping ? Minimum stable flow, overload optimisation (not critical)

Possible mitigations:

- Not relevant

Operational complexity of allocation process

<table>
<tr><th>Common Order Books</th><th>Preliminary Order Books</th><th>Explicit Auctions</th><th>Intraday Price Coupling</th><th>Separate Day Ahead Coupling</th></tr>
<tr><td colspan="2">× Double matching process with multiple interfaces between different processes/ operators (BBZ flow calculation, MRLVC, SDAC, GB DAM)
× Lack of time to identify and correct any errors – issues or delays likely to cause decoupling of MRLVC
× Dependent on SDAC which already has high operational complexity and issues – e.g., large number of parties</td><td rowspan="2">✓ Low complexity
✓ Independent processes with own backup arrangements</td><td rowspan="2">✓ Modest complexity: single matching process (price coupling) with few interfaces; few parties involved</td><td rowspan="2">✓ Modest complexity: single matching process(price coupling) with few interfaces; few parties involved</td></tr>
<tr><td></td><td>× Additional NEMO processes to validate and transmit preliminary order books; increased risk of operational errors</td></tr>
</table>

Possible mitigations:

- Well integrated operational processes (process simplification; common communications protocols)
- Coordinated incident management, backup procedures

Futureproofing

Common Order Books	Preliminary Order Books	Explicit Auctions	Intraday Price Coupling	Separate Day Ahead Coupling
✓ MRLVC able in principle to accommodate additional ICs, 15-minute settlement, additional PXs × Difficult to extend to IDA (processing time) × Basic DAM model for GB depends on SDAC (timing, products, concept): future evolution in GB (e.g., greater role for intraday) may depend on changes to IEM	(as for Common Order Books)	✓ Flexible solution, supporting new ICs or timings ✓ Independent from IEM, able to evolve towards different solutions going forward × Efficiency of explicit auctions deteriorates if market spreads narrow, as is forecast	✓ Independent from IEM, able to evolve different DA solutions going forward ? Ability to continue once intraday auctions are recognised as part of the IEM × Unbalanced solution for GB-SEM-EU once SEM physically connected to SDAC.	✓ Solution able in principle to accommodate additional ICs, 15-minute settlement, additional PXs ✓ Independent from IEM, able to evolve different solutions going forward × Difficult to apply to ID: excessive number of ID auctions

Possible mitigations:

- Ability to withdraw from MRLVC in future

Operational impact on SDAC

Common Order Books	Preliminary Order Books	Explicit Auctions	Intraday Price Coupling	Separate Day Ahead Coupling
× Any reduction on SDAC processing time could impact performance (i.e., optimality of SDAC results); time pressure likely to increase with 15-minute settlement × Any reduction on MRLVC processing time could impact performance – e.g., increased price discrepancies × Any delay to SDAC would restrict backup options, given 1530 window	✓ Limited impact, depending on fallback procedures	✓ No impact, completely separate process	✓ No impact, completely separate process/timeframe	✓ No impact, completely separate process

Possible mitigations:

- Accelerating MRLVC algorithm: focus on resolving flows at times of no congestion; simplify treatment of complex orders (which could have particular implications for markets such as the SEM where such orders are widely used)
- Close coordination of backup processes, incident management
- Earlier gate closure time/later publication time/some parallel processing

Roles and governance

Common Order Books	Preliminary Order Books	Explicit Auctions	Intraday Price Coupling	Separate Day Ahead Coupling
× Four separate governance jurisdictions to be coordinated • MRLVC MCO • BBZ flow forecaster • SDAC • GB DAM × Complex issues: • operations • changes • performance (MRLVC very dependent on BBZ forecast) × Impacts vary by IC × Large number of parties; some differing priorities	Similar to Common Order Books	✓ Discrete, interconnector-specific operations with largely independent governance ✓ Few, task-specific, common service providers (e.g., JAO, RNP)	✓ Single MCO operation with associated governance ✓ Multi-PX environment in GB already established	✓ Single MCO operation with associated governance

Possible mitigations:

- Careful design of governance arrangements – in particular, addressing points of possible conflict or delay (e.g., operations, change management)

Principal roles and organisation

Function	Role	Key Parties	Governing framework
MRLVC (new)	• MRLVC computation • Operational management • Shipping	• GB and EU TSOs • [GB PXs and BBZ NEMOs]	• Joint cooperation agreement • TSO regulation
BBZ Flow Forecast (new)	• Bordering Bidding Zone Flow Forecasting	• EU TSOs	• ENTSO-E?
SDAC (existing)	• SDAC price coupling and associated processes	• SDAC TSOs • SDAC NEMOs	• CACM and associated Methodologies
GB Price Coupling (new)	• GB price coupling and associated processes	• GB PXs • [GB TSOs]	• Joint cooperation agreement

- Four distinct functions, each with its own separate governance arrangements
- Requires overall mechanisms to align and coordinate the four functions – e.g.: MRLVC lead coordination on MRLVC operational performance, changes

MRLVC Governance (I)

Element`	Comment
GB and EU TSOs have joint responsibility under the TCA for setting up and operating MRLVC, under NRA supervision	• TSOs should have primacy in regards to all decisions regarding MRLVC: design, appointment/ management of service providers, etc • TSOs should bear the costs of MRLVC, subject to NRA approved recovery *Issue: given that interconnector TSOs are primarily impacted by the performance of the MRLVC, should they rather than all TSOs take the lead?*
GB PXs and Bordering BZ NEMOs need to comply with and support MRLVC arrangements – e.g.: • Submission of order books • Operational procedures • Shipping • Admission of new parties • Change management	Requires a joint governance framework between TSOs and GB PXs/BBZ NEMOs setting out roles, responsibilities, decision-making, liabilities and obligations, cost sharing/recovery, etc Implies joint cooperation agreement model (as used in other coupling initiatives) *Issue: will this require a supporting regulatory obligation on NEMOs (CACM?) and GB PXs (new)?*

MRLVC Governance (II)

Element`	Comment
SDAC needs to align with and support MRLVC arrangements – e.g.: • Acceptance of MRLVC results • Common operational procedures • Change management	Requires appropriate modifications to current SDAC rules and procedures *Issue: does this require changes to CACM?*
BBZ flow forecasting needs to comply with and support MRLVC arrangements – e.g.: • Submission of BBZ flow forecast • Operational procedures • Change management	Requires appropriate rules and procedures to be established in the new BBZ Flow Forecasting function *Issue: will this require a supporting regulatory obligation on EU TSOs?*

MRLVC MCO options

Option	Discrete legal entity	Service, contracted by TSOs	Service, provided by NEMOs/PXs
Description	Independent entity established by TSOs, owning and operating the MRLVC systems	MRLVC MCO function provided by one or more service provider under service contract, following tender	MRLVC MCO function provided by NEMOs/GB PXs (e.g.: rotating the responsibility), under joint cooperation agreement with TSOs
Example	JAO, EMCC	SEMO-GB ID	CWE, MRC
Advantages	• Potential to be directly regulated (by whom?)	• Direct control over critical business function for TSOs • Relevant prior models	• Relevant prior models • Potential speed of implementation • Build on and align with existing capabilities
Disadvantages	• Costly to establish entity with right resources and capabilities • Joint regulation (by ACER/Ofgem?) • Does not simplify governance challenges	• Procurement delay to project • Limited number of potential providers with suitable experience and competency (e.g., able to use Euphemia)	• Not a critical business function for PXs/NEMOs • Basis for cost recovery given no competitive tender

Possible GB organisation

Element	Comment
GB DAM MCO provided by GB PXs	• Proven model in PCR: PXs have right competences and incentives • Neutralises any competitive advantage • Hot backup possible
GB DAM open to any qualified GB PX (no regulatory obligation)	• PXs are commercially highly incentivised to take part
Governed under joint agreement with GB TSOs	• ITSOs have an interest: necessary to enable MRLVC • Arrangements largely self-governing, normally requiring no TSO action (some exceptions – e.g.: admission of new PX and whether can be MCO, sanctions for poor performance) • Arrangements subject to Ofgem approval via TSO regulation
Transparency obligations (operational performance; changes; other decisions)	• Visibility to the market participants provides reassurance and an effective way to deter competitive strategy considerations from impacting decision-making
PXs bear costs of MCO and their own costs of interfacing to the MCO	• Assumes no exceptional new costs (like new algorithm) • Inter-PX settlement costs should be addressed as part of MRLVC shipping arrangements

Implementation ease/speed

Common Order Books	Preliminary Order Books
× Significant new business processes to be implemented (systems, organisation, operational procedures, agreements, regulatory approvals/changes) × Four discrete groups (MRLVC, SDAC, BBZ flow forecaster, and GB DAM) which need to coordinate closely with each other × Lack of established frameworks in which to undertake the implementation task (e.g., organisation and resources, decision-making, funding): MRLVC, BBZ flow forecaster, GB DAM × Lack of fully aligned interests among all key parties × Reliance on a novel concept not yet prototyped (BBZ flow forecast) × Potential requirement to undertake tenders for systems, service providers × Potential impact of needing regulatory changes (in particular, CACM) ✓ Potential to re-use/modify existing solutions (technical, contractual) ✓ Potential to adopt cooperation approach used successfully in earlier projects (e.g., TLC, CWE, NWE) ✓ Potential to establish a lean project structure, delegating responsibility to a core group of parties	Similar to Common Order Books

Implementation Tasks

MRLVC

Task	Estimated time	Key drivers
New IT systems (including algorithm, communications) development and testing	3-24 mo	• Ability to use/modify Euphemia and PCR Matcher Broker systems and communication protocols
Operational procedures development and testing	6-18 mo	• Appointment of MCO(s) • MCO's familiarity with SDAC procedures • Complexity of operational procedures (e.g., fallback); interaction with SDAC/GB
Contractual arrangements including cooperation agreements, SLAs	6-12 mo	• Ability to re-use pre-existing agreements • Agreement on cooperation principles; negotiation of terms (e.g. with PXs)
Regulatory changes	3-12 mo	• Need for and nature of regulatory changes • Individual NRA processes
Procurement of MRLVC MCO operator(s)	3-9 mo	• Decision to tender or seek PX/NEMO cooperation
Parallel run to confirm methodology	3-12 mo	• Ability to test model against historic data • Market participants' requirements
Shipping arrangements	6-12 mo	• Re-use of existing methods • Complexity of arrangements • Resolution of the terms (e.g., charges)

Implementation Tasks

BBZ Flow Forecaster

Task	Estimated time	Key drivers
BBZ flow forecaster development and testing	9-18 mo	• Finding a feasible methodology (performance, auditability, reproducibility) • Input data complexity/availability • Performance evaluation (with MRLVC)
Operational procedures development and testing	3-6 mo	• Assignment of operator(s)
Contractual arrangements including cooperation agreements, SLAs	3-9 mo	• Ability to re-use pre-existing agreements
Regulatory changes	3-12 mo	• Need for and nature of regulatory changes • Individual NRA processes
Procurement of operator(s)	3-12 mo	• Decision to tender or appoint a service operator
Parallel run to confirm methodology	3-12 mo	• Ability to test model against historic data • Market participants' requirements

Implementation Tasks

SDAC

Task	Estimated time	Key drivers
Changes to BBZ NEMO and PCR IT systems	6-12 mo	• Degree of change (Preliminary Order Books option may require more changes)
Operational procedures development and testing	6-18 mo	• Impact of required changes (e.g., new Gate Closure Time, fallback procedures) • Coordination with MRLVC
Changes under CACM	12-18 mo	• Need to modify Methodologies • Need to undertake consultation • Need to amend CACM; possibility of derogations
Parallel run to confirm methodology (with MRLVC)	3-12 mo	• Ability to test model against historic data • Market participants' requirements

Implementation Tasks

GB Price Coupling

Task	Estimated time	Key drivers
New IT systems (including algorithm, communications) development and testing	3-18 mo	• Ability to use/modify Euphemia and PCR Matcher Broker systems and communication protocols
Operational procedures development and testing	6-12 mo	• Complexity of operational procedures (e.g., fallback); interaction with MRLVC
Contractual arrangements including cooperation agreements, SLAs	6-12 mo	• Ability to re-use pre-existing agreements • Agreement on cooperation principles; negotiation of terms
Regulatory changes	3-12 mo	• Need for and nature of regulatory changes or approvals
Procurement of MRLVC MCO operator(s)	3-12 mo	• Decision to tender or seek PX/NEMO cooperation
Parallel run to confirm methodology	3-12 mo	• Ability to test model against historic data • Market participants' requirements
Inter-PX settlement	6-12 mo	• Re-use of existing methods • Alignment with MRLVC arrangements • Resolution of the terms (e.g., charges)

Critical implementation tasks

Task	Lead parties	Time	Dependencies
Establish MRLVC project (steering committee, cost sharing, project agreement, support)	Directly connected TSOs	2-4 mo	• Agreement on role of GB PXs/BBZ NEMOs (may need legal check) • Cost recovery arrangements • Agreement on involvement of all TSOs
Establish coordination framework with SDAC, GB DAM, BBZ flow forecaster	MRLVC SC (+ EC, BEIS and NRA support)	1-2 mo	
Establish BBZ flow forecaster project (steering committee, funding, support)	EU TSOs (potentially ENTSOE)	1-2 mo	• Cost recovery arrangements
Undertake BBZ flow forecaster methodology R&D; testing	EU TSOs MRLVC (testing)	4-6 mo	• Appointment of expert resources
Assess options for procuring MRLVC MCO and algorithms/systems	MRLVC SC	2-4 mo	• Clarity on availability of existing solutions
Determine critical changes to SDAC; identify impact on CACM and Methodologies	SDAC SC	4-6 mo	• Decision on Common Order Books option
Establish GB DAM project (steering committee, cost sharing, project agreement, support)	GB TSOs GB PXs (+ BEIS/Ofgem)	2-4 mo	• Agreement on role of GB PXs and TSOs • Cost recovery arrangements
Project Initiation: plan, deliverables, budget, updated CBA	4 relevant SCs	2-4 mo	• Established projects • Clarity on high level design issues

Bold indicates tasks with the highest impact on the critical path

Cost of implementation

Common Order Books	Preliminary Order Books
× Significant new business processes to be implemented (systems, organisation, operational procedures, agreements, regulatory approvals/changes) × Complex programme management across many parties and four discrete groups (MRLVC, SDAC, BBZ flow forecaster, and GB DAM) × Doubtful benefits from tendering (limited number of qualified providers) ✓ Potential to re-use/modify existing solutions (technical, contractual) ✓ Potential to adopt cooperation approach used successfully in earlier projects (e.g., TLC, CWE, NWE) ✓ Potential to establish a lean project structure, delegating responsibility to a core group of parties	Similar to Common Order Books

Implementation Costs

- Implementation costs can vary considerably – e.g.:

Trilateral Coupling (TLC)	~ €6 mil	28 months	3 PXs; 3 TSOs
Central West Coupling (CWE)	~ €33 mil	35 months	3 PXs; 6 TSOs

- The principal cost elements are typically:
  - IT systems development (algorithms, data management and communications)
  - Internal experts (market design, operations, legal and commercial)
  - Testing
  - Project management
- The main drivers of cost are:
  - Ability to re-use or modify existing solutions (technical, operational and contractual)
  - Novelty of the problem, need for R&D (relevant to the BBZ flow forecaster)
  - Complexity, including the number of involved parties
  - Implementation time
- A realistic cost estimate is possible once the principal elements are known:
  - High level functional architecture and impact assessment
  - Re-use, modification or new development of the main IT elements
  - Roles and responsibilities, including basis for cost sharing
  - Approval process, including testing and parallel running

Cost of operation

Common Order Books	Preliminary Order Books
✗ Significant new business processes: MRLVC, BBZ flow forecaster, and GB DAM ✗ Doubtful benefits from tendering (limited number of qualified providers) ✗ Shipping can cause material incremental costs ✓ Operational tasks normally involve limited manhours and can utilise existing IT and staff resources in certain organisations ✓ Potential to adopt cooperation approach used successfully in earlier projects (e.g., TLC, CWE, NWE) ✓ Potential to optimise shipping arrangements	Similar to Common Order Books

Cost of operation

- The principal operational cost elements are typically:
  - IT systems maintenance
  - Shipping (e.g., clearing house charges)
  - Operations
  - IT operations and communications
- The main drivers of cost are:
  - Efficient design of the arrangements, minimising additional costs
  - Basis for costing (commercially set fees, incremental actual costs, etc)
  - Cost sharing and recovery – what share is borne by whom
- A realistic cost estimate is possible once the principal elements are known:
  - Joint use of main IT elements (and associated cost sharing principles)
  - Roles and responsibilities, including basis for cost sharing/recovery
  - Shipping solution
- By way of illustration, the approach in CWE was to pay the PXs a fee per MWh shipped cross-border to cover operation of both the MCO and shipping. For a 1GW interconnector available 95% of the time where the coupling allocates an average of 60% of the ATC, a fee of €0.04 corresponds to a charge of €200k pa at each end.

Contents

Detailed design options

To inform the future detailed development of the MRLVC, we also assessed advantages and disadvantages of detailed design features associated with the high-level MRLVC options

Aspect	Options
1. **Treatment of MRLVC-determined IC flows in SDAC/GB** *(common feature of both assessed MRLVC options)*	a) Price taking orders - base case b) Limit orders in SDAC c) ‘Flexible market coupling orders’ in GB
2. **GB price formation** *(common feature of both assessed MRLVC options)*	a) GB price coupling – base case b) Independent GB price computation
3. **Operational timeline** *(consequence of Common Order Books option)*	a) Earlier gate closure time, at least for GB/bordering BZs b) Delay publication time for SDAC
4. **Process completion** *(issue for both assessed MRLVC options)*	a) MRLVC PTOs are firm, at least for SDAC – base case b) Mutual completion confirmation required from both GB and SDAC before either can report firm results
5. **Long-term rights** *(possible mitigation measures for both assessed MRLVC options)*	a) PTRs: Use-it-or-lose-it (UIOLI) rather than Use-it-or-sell-it (UIOSI) b) PTRs/FTRs: cap payout

1. Treatment of IC flows

Limit orders on SDAC

Description	• Base case in tight volume coupling is to treat the IC flows as price taking orders (PTOs) in the subsequent price matching processes – ensures flow is exactly fulfilled
	• Alternatively, treat the MRLVC-determined IC flows as limit orders on SDAC
	  • Limit price equal to MRLVC-anticipated GB price, adjusted for losses
	  • Resulting matched volume on SDAC then used as PTO on GB DAM

Advantages	• Reduce likelihood and severity of flows-against-price-difference (FAPDs) which cause
	  • negative congestion revenue (after losses)
	  • opportunity costs (unrealised potential congestion revenue)
	  • unhedged UIOSI/FTR payments (vs congestion revenue)

Disadvantages or issues	• GB DAM results not available until about 10 minutes after SDAC • Issue whether SDAC results would remain non-firm until GB successfully matches – align with current process final validation of SDAC results? Other risk mitigation options? • Resulting flows may not comply with period-to-period ramping constraints • Difficult to assess quantitatively without the BBZ flow forecaster solution
Recommendation	• **Keep as a contingency option if standard (PTO) MRLVC with BBZ flow forecaster results in unacceptable risk of FAPDs** • **Some ICs could stay with PTOs (e.g., to support ramping)**

Price vs Limit Orders

Standard LVC – Price Taking Orders

- MRLVC midpoint flow: 100MW (uncongested)
- MRLVC anticipated prices (not used in Standard LVC):
  - GB: 50 EUR/MWh
  - XX: 49 EUR/MWh
- Price Taking Orders (match volume at any price) in relevant DAMs simultaneously:
  - GB: sell 99MW (2% loss factor)
  - XX: buy 101MW
- Results in FAPD if SDAC price in XX is more than 49 EUR/MWh (assuming GB is 50 EUR/MWh)

LVC + Limit Orders

- MRLVC flow and anticipated prices same
- Step 1: Limit Order (match volume if price condition met) in SDAC XX:
  - Buy 101MW if price <=49* EUR/MWh (limit price based on anticipated GB price adjusted for losses)
- Flow depends on SDAC result:
  - If XX price less than or equal to 49 EUR/MWh, 101MW matched
  - If XX price more than 49 EUR/MWh, no match and flow is zero
- Step 2: PTO in GB DAM for resulting flow
  - Sell zero or 99MW (loss adjusted)
- Eliminates FAPDs (unless GB price can also vary – e.g., due to other ICs)

1. Treatment of IC flows

‘Flexible market coupling orders’ in GB

Description	• Rather than a simple price taking order, the IC flow is treated as an order with a small volume increment/decrement around the price the MRLVC expects in the adjacent BBZ, adjusted for losses • Only used where the flow is uncongested
Advantages	• Avoids uncongested price discrepancies caused by price verticals in the GB matching, where the GB price would be set by local rules (min, average or max): enables effective sharing of BBZ price • Halfway step towards price coupling as used by EMCC to Denmark
Disadvantages or issues	• Approach designed for improving tight volume coupling but less applicable to loose coupling • MRLVC unlikely to be able to forecast BBZ prices correctly • Price verticals less likely to be an issue given multiple interconnectors and size of GB market
Recommendation	• **Unlikely to be relevant, but retain as an option during development and testing of MRLVC**

2. GB price formation

Independent GB price computation

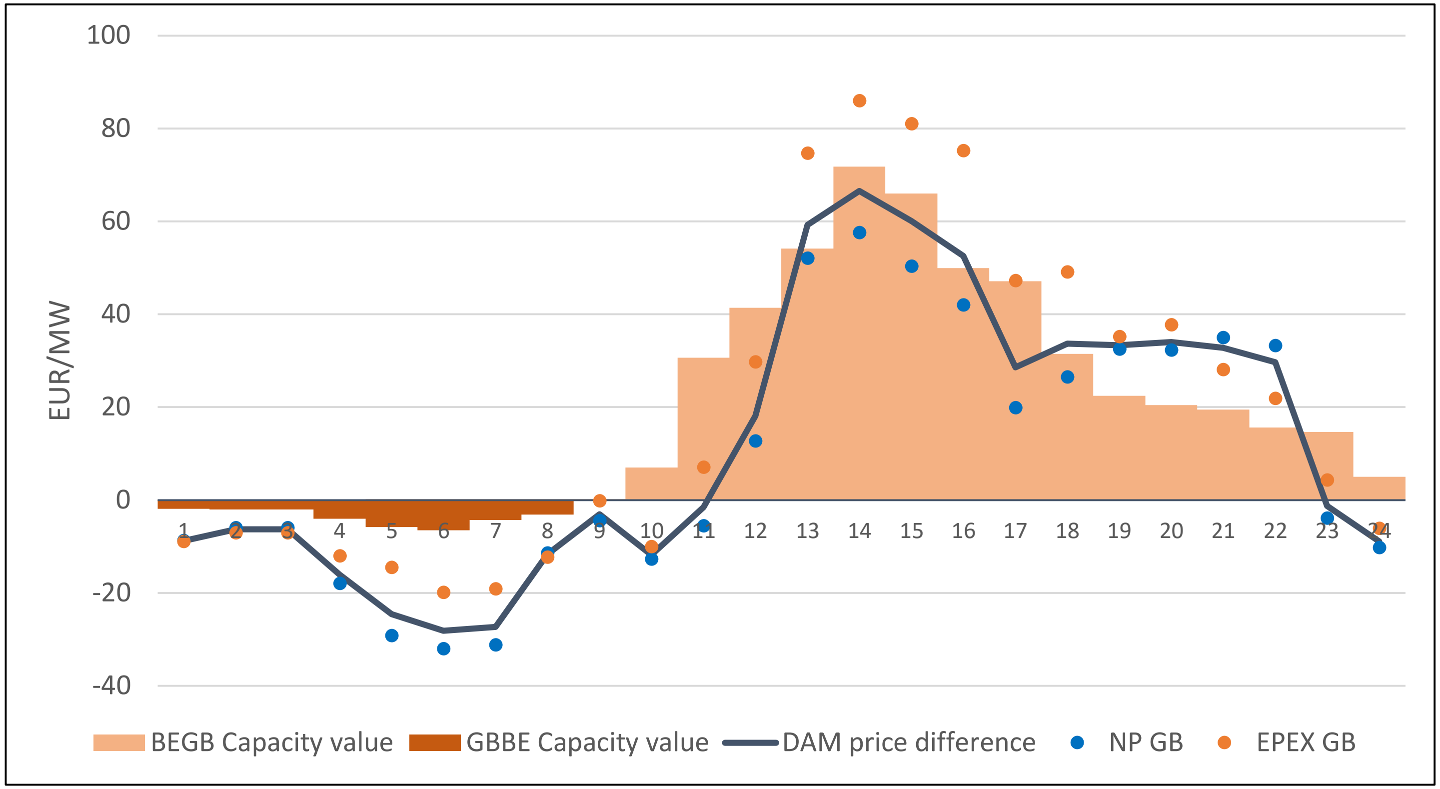
Description	• Base case in SDAC/MRC is to ensure a single GB price by determining the GB price in a subsequent GB price coupling following MRLVC • Alternatively, the GB PXs could be (tight) volume coupled via MRLVC, with each PX then independently calculating its own price
Advantages	• Avoids need to establish and maintain a GB price coupling

Disadvantages or issues	• GB prices likely to differ due to the normal issues in volume coupling (incomplete optimisation; price indeterminacy): negative impact on price formation, establishment of reference prices and market/NRA perception
	• Different GB prices significantly complicates shipping/choice of shipper, and inter-PX settlement
	• Further complicates the fallback/coordination procedures
	• Even without a GB coupling, key PX-PX and PX-TSO coordination issues remain – e.g.:
	  • Cross-border and inter-PX shipping arrangements
	  • Max-min price alignment; common foreign exchange rates
	  • Cost sharing/recovery
	  • Change requests (e.g., new products)
	  • Conditions for participation, admitting new PXs

Recommendation	• **Retain a GB price coupling, building on prior experience**

Impact of DAM fragmentation

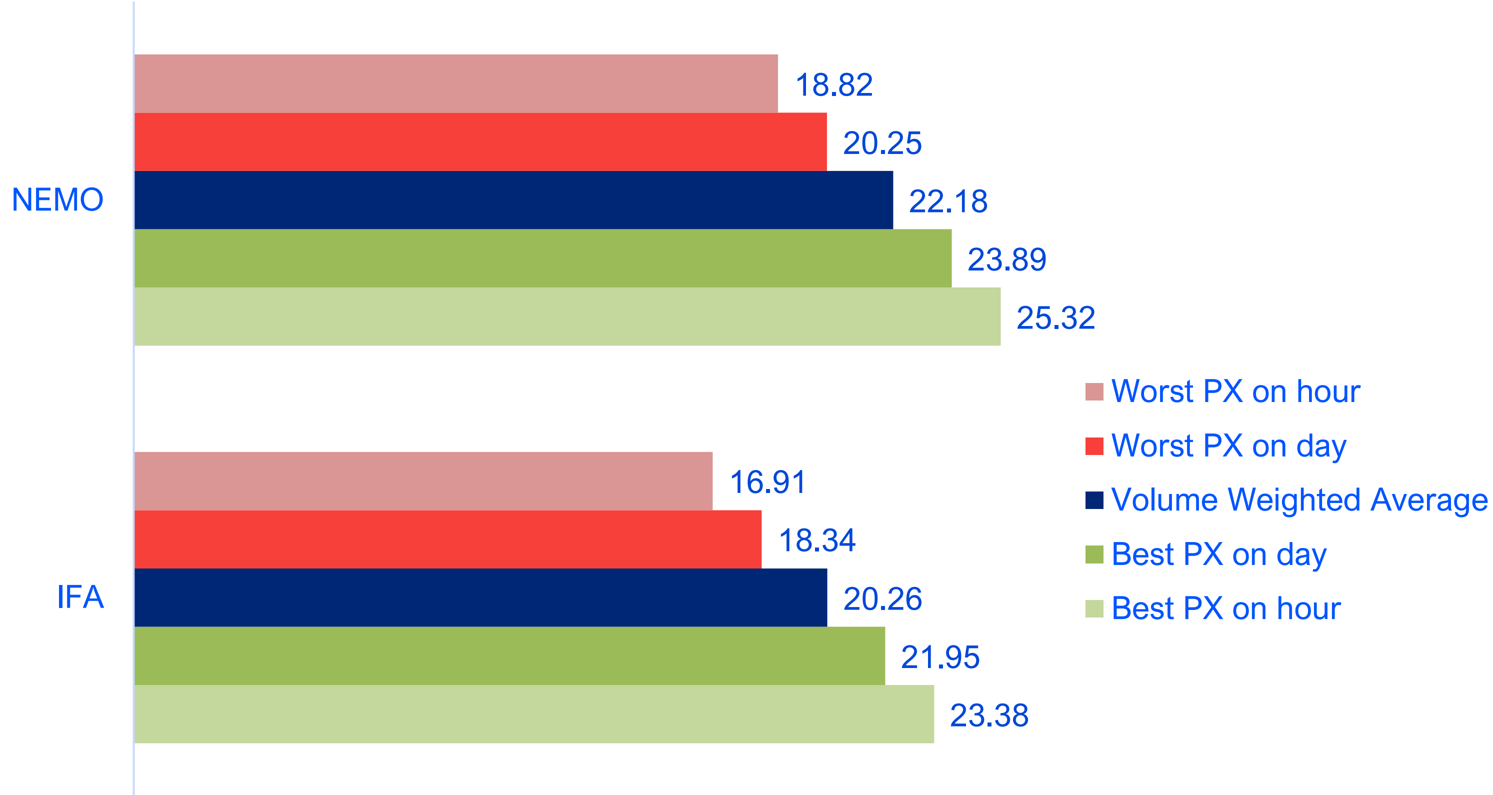
NEMO, 28 March 2021



- Illustrates the range of GB DAM prices relative to the value of interconnector capacity (explicit allocation)
- If volume coupled, the GB DAM prices would be probably be close but not necessarily the same

Impact of DAM fragmentation

Average absolute LAPD (€/MWh), actual, Q1 2021



- Price differences between N2EX and EPEX on GB DAM are significant relative to the value of capacity
- Added uncertainty/risk for traders: likely to result in reduced value for capacity

3. Operational timeline

Earlier gate closure or later results

Description	• Use of common order books in MRLVC and SDAC will delay the start of the SDAC MCO processing (requires final IC flows to/from GB) - not relevant to Preliminary Order Book option
	• This extra time can be found by any combination of earlier gate closure time on GB and all SDAC/just BBZ or later results publication
	• Background on timings:
	  • SDAC aims to publish preliminary results at 12:45 (new timing) with a final confirmation at 12:55
	  • In ITVC, CWE normally published results at 12:45, Nordic 5-10 minutes later

Advantages	• Avoids problems of reliance on preliminary order books • Avoids need to restrict SDAC processing time, which would impact optimality of SDAC matching and could increase risk of decoupling
Disadvantages or issues	• Trading is effectively suspended while waiting for results. Market parties strongly prefer shorter delays, but 45-55 minutes was accepted previously on ITVC/CWE/Nordic • Mixed SDAC gate closure times may cause confusion/errors • Later publication of results would impact backup procedures, already constrained by 15:30 deadline for TSO nominations in CWE
Recommendation	• **Primarily an issue for SDAC to review timings and other options to mitigate impact - e.g., parallel computation using estimated IC flows; revised fallback procedures**

4. Process completion

Mutual completion confirmation

Description	•	Both GB and SDAC have to confirm to each other that they have successfully finished before either can report firm results (Kontek and ITVC model)
Advantages	•	Avoids risk of either SDAC or GB DAM not matching, leading to imbalanced position for IC
Disadvantages or issues	• • •	Additional operational step of confirming completion A problem in the GB matching could trigger SDAC fallback Implies SDAC waiting 10-15 minutes under the ‘limit price enhancement’ for the subsequent GB DAM matching to complete
Recommendation	• • •	**Develop and test design on basis of no mutual confirmation** **GB should opt to wait for SDAC, in case of operational incidents (but not vice versa given more operational flexibility in GB); ensure sharing of progress status between GB and SDAC** **TSOs need to be able to trade out any unmatched position (in fallback DAMs, continuous markets or other arrangements used for outage management)**

Backup/Fallback procedures

Principles

1. Aim to ensure orderly energy markets in SDAC and GB – in particular:
    - Market participants should know the grid topology and interconnector capacities relating to the markets they are bidding into, and how capacity on any decoupled interconnection will be allocated
    - Implicit allocation of capacity is as efficient as possible (e.g., using the correct order books)
2. Avoid creating any additional risk of decoupling (partial or full) to SDAC
3. Use capacity as optimally as possible, subject to #1 and #2

Proposed MRLVC fallback procedure

- MRLVC-determined IC flows set to zero
- Capacity allocated in intraday arrangements rather than use shadow auctions (avoid delay to SDAC; poor shadow auction valuations; reduced operational complexity for all)
- GB DAM rerun in isolated fallback mode

Proposed MRLVC Processes

Incident	Proposed MRLVC Process	Comment
1. Missing network data in IEM leading to partial decoupling (deadline 11:45)	MRLVC entitled to cancel* on one or all ICs (deadline [11:50])	Cancel only where Bordering BZ flow forecast likely to be materially wrong
2. SDAC operational errors, delay	MRLVC-determined flows remain firm at IC TSOs' discretion	Provided there are no changes to the OBs used by MRLVC
3. Partial decoupling declared in SDAC (deadline 12:40)	MRLVC automatically cancelled*, unless agreed otherwise with SDAC incident committee	Least risk for SDAC; under SDAC control
4. Full decoupling in SDAC	MRLVC cancelled*	No alternative
5. MRLVC operational errors, delay	MRLVC automatically cancelled* after [15] minutes delay, unless agreed otherwise with SDAC incident committee	Avoid additional risk to SDAC; extension under SDAC control
6. GB matching operational problems	IC flows remain firm: SDAC unaffected	ICs manage any imbalance in GB

5. Long-Term Rights

UIOLI

Description	• Base case assumes either FTRs or PTRs based on the European standard (i.e. UIOSI) are offered • Alternatively, PTRs could be offered on a UIOLI basis on some borders (rather than FTRs)
Advantages	• Depending on the looseness of the MRLVC, TSOs could face significantly higher UIOSI payouts compared to the congestion revenue received; this risk is entirely removed with UIOLI • UIOLI was the standard form of long-term capacity right until about 10 years ago
Disadvantages or issues	• Market parties prefer UIOSI: the right to physically nominate is rarely used in well-developed day-ahead markets • Market parties would pay less for a PTR without UIOSI • NRAs may expect UIOSI
Recommendation	• **UIOLI should remain a contingency option, depending on the quality of the eventual MRLVC solution**

5. Long-Term Rights

Cap payout

Description	• Base case assumes either FTRs or PTRs based on the European standard (i.e., UIOSI for PTRs) are offered • Alternatively, either PTRs or FTRs could be offered with the payout limited – e.g. to the congestion revenue received by the TSO, or no payout for periods with FAPDs • Some precedent: UIOSI already reduced by transmission losses or periods of curtailment
Advantages	• Reduces or potentially removes risk faced by TSOs that UIOSI payouts are higher than the congestion revenue
Disadvantages or issues	• Exposes market participants to the errors caused by loose volume coupling, reducing its value as a hedge between markets • Market parties would pay less for a FTR/PTR with a capped payout
Recommendation	• **Capping should remain a contingency option, depending on the quality of the eventual MRLVC solution** • **Preferable to abandoning LT rights (let market decide if they are of value)**

Annex – detailed findings of literature review

Drivers of volume coupling

	Finding	Implications for MRLVC
1	The move towards implicit allocation arises from the observed inefficiency of explicit allocation, resulting in less social welfare, less price convergence, higher price volatility and more frequent adverse flows [15, 16]	The most recent performance of explicit auctions supported by current technologies needs to be assessed
2	Volume coupling was originally seen as a potential way to link regions where each may have a different regional solution – the 'Dome Coupling' concept [3]. Advantages over price coupling [17]: • Region-specific organisation/governance structures can remain in place • No requirement to completely harmonise products and price determination rules • Better acceptance insofar as one region is not "taken over" by another	MRLVC enables a separation of GB and SDAC into independent regional arrangements
3	The main advantage of volume coupling was thought to be that it would be easier to implement, requiring less harmonisation of rules, governance and algorithms [2]. However, in reality volume coupling faces similar technical and governance/control issues to price coupling [3].	While MRLVC will operate in a distinct operational environment, there will still need to be coordinated governance between MRLVC, SDAC and GB DAM

Design of volume coupling

	Finding	Implications for MRLVC
4	The quality of the volume coupling can be adjusted, from 'loose' to 'tight', dependent on how well the flow calculation has replicated the bids and local market rules of the individual price determinations. This can impact the degree to which prices fully converge or capacity use is optimized [3]. Small differences in the matching algorithm may be unavoidable, but differences in network data, market data or market rules are a design choice [16]	MRLVC should aim to be as tight as possible consistent with the limitations on data established in the TCA
5	A consequence of loose coupling is not only adverse flows but also situations when transmission capacity may not be fully utilised even though the local power exchange prices are different [15]	Effects of adverse flows and under-utilisation both need to be evaluated
6	A multiregional loose volume coupling solution was evaluated for Nordic-CWE in 2009: 'loose' because only order books from adjacent CWE BZs would be included (NL, DE) [16]. Critical issues identified with loose volume coupling: • Poor economic performance (unacceptable loss of social welfare and intolerable price discrepancies) • Poor operational robustness ('double matching' issue) • Poor acceptability to stakeholders	Proposed model similar to MRLVC but without BBZ flow forecasting. Qualitative and quantitative assessment should include these topics, and can build on this analysis

Operational features

	Finding	Implications for MRLVC
7	Volume coupling is a sequential process using the same order books as the subsequent order matching/price setting. This ITVC process added approximately 15 minutes [6, 20].	Using the same order books as SDAC/GB implies additional time between gate closure and SDAC/GB results publication
8	Volume coupling is operationally complex, involving at least 3 separate computations with coordination between them [1]. Price coupling is a single step which better guarantees the robustness of the calculation [7, 16].	While SDAC is already operationally complex, MRLVC adds operational interactions and dependencies. The design should seek to minimise these.
9	On 5 August 2013 Nord Pool was unable to match the Nordic region, and reverted to the prices and results for 2 August (in accordance with its rulebook) [19]. However, CWE had already matched based on the ITVC calculated flows for that day. This resulted in very significant imbalances on the interconnectors	Robust processes needed to confirm successful matching in both SDAC and GB before either results are final
10	An incident in the Multi-Regional Coupling process led to a partial decoupling of one NEMO in CWE. As a consequence, and in the absence of suitable multi-NEMO arrangements, three interconnectors were forced to decouple [12]	The MRLVC shipping arrangements on each border should be capable of operating even if an individual NEMO/PX is forced to decouple

Performance challenges

	Finding	Implications for MRLVC
11	The volume coupling should not create any inefficiencies or adverse flows provided three conditions are met [2]: • The three computations (volume coupling and price matching at either end) work using similar objectives, constraints and data • There is a unique optimal solution, or if not procedures are needed to select one where more than one is optimal • The three computations successfully find the optimal solution. This can be an issue if processing time is constrained, which it usually is because of market pressure	As a loose solution, MRLVC cannot meet these conditions • MRLVC only sees a subset of the SDAC objective, constraints and data • Probably not feasible given the operational complexity • In MRLVC the three computations will not find the same optimal solution, even with more time
12	Even tight volume coupling is prone to result in 'flows against price differences' or 'adverse flows', where the import BZ price is lower than the export BZ price. This can be for a variety of reasons – for example, on Kontek an EMCC presentation [8] listed four explanations: poorly designed rounding procedures; different currency conversion rates; differing price caps; and, block bid selection.	Even in a loose coupling, minimising these effects is valuable
13	The computations are made significantly more difficult due to the presence of block orders. This creates a Mixed Integer Problem that cannot always be optimised within a reasonable time [10, 11].	MRLVC will also need to support block orders
14	Volume coupling together with the matching computations requires careful implementation and ongoing change management, including adequate testing, to avoid potentially catastrophic errors. The first volume coupling on Kontek was withdrawn after only 10 days because of issues over algorithm consistency [1].	Both the initial implementation and all subsequent changes need to be carefully managed and tested end-to-end

Performance mitigations

	Finding	Implications for MRLVC
15	An alternative optimisation methodology has been proposed that relaxes the uniform pricing condition, allowing paradoxically accepted blocks [13]. This 'non-uniform pricing' model was presented to the European Stakeholder Committee [14]	Given that MRLVC is not calculating prices, this could be a way to significantly speed up the computation with minimal impact on the results
16	Price indeterminacy on an uncongested border is where the result coincides with a price vertical in the net export curve of one or other market. In a price coupling, the price would be determined by the other market. In volume coupling this can lead to significant uncongested price discrepancies. Each PX will have rules to set prices in such a situation (min, max or midpoint). Solutions have been developed to enable sharing of the anticipated price in one market with the other. The volume coupling flow and anticipated price in BZ_A are used to create a order on BZ_B with small volume and price flexibilities. Can use a Virtual area coupling or Flexible market coupling orders [18, 19]. Adopted on Kontek II [2] and ITVC.	This approach was a way to reduce uncongested price discrepancies in a tight volume coupling (and get close to a price coupling in one direction). Quantitative modelling will indicate whether this could have any value in a loose coupling, given that MRLVC will be unable to predict BBZ prices very accurately. A possible design option
17	Pricing is easier (i.e., the problem of indeterminate prices) if the net export curves are continuous or at least have small steps. This tends to be a function of market size, and was an issue for East Denmark in the Kontek coupling [1].	Price indeterminacy is likely to be less of an issue due to GB market size and use of piecewise linear bids rather than steps
18	Classical volume coupling (such as ITVC) could be improved if the data from the volume coupling solver is then used to 'hot start' and accelerate the subsequent matching computations [2]. This would, however, imply a strong level of coordination, perhaps even common operation.	Unlikely that MRLVC can help hot start SDAC given that (i) it is only solving bordering BZs and (ii) MRLVC-SDAC operational integration is not permitted

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