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Making Future

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Stability market design – Modelling

Modelling annex for National Grid ESO

MARCH 2022

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This report focusses on the quantitative assessment of the stability landscape (2d.)

1 Alignment, vision, objectives

1a. Scene setting

What are the realities? Establish 'givens' and make assumptions on all relevant topics

1b. Objectives

What do we want to achieve? Establish the design principles for the market

2 Design elements, strengths, weaknesses

2a. Market building blocks

Define the key design choices that can materially impact market outcomes

2b. Straw-man options

Define conceptual design options to assess – exploring alternative philosophies

2c. Assessment

Appraise design options qualitatively and **(2d.) quantitatively** against objectives

3 Industry views, refinement, finalisation

3a. Refinement

Highlight the preferred option; make improvements to increase performance against our objectives

3b. NIA desirable option

Recommend a desirable design for stability market and way forward

Stakeholder engagement has fed into our assessment

STABILITY MARKET DESIGN

Contents

STABILITY MARKET DESIGN – MODELLING ANNEX

1. Summary & conclusions

We have modelled a range of scenarios and sensitivities to understand the impact of various design choices

Base scenarios *(2026 and 2030)*

FES 2019 – Two Degrees (TD)

- Characterised by rapid decarbonisation, with large centralised (but still intermittent) generation.
- Primarily growth in generation is driven by increased deployment of offshore wind.

FES 2019 – Community Renewables (CR)

- Rapid decarbonisation driven by decentralised generation.
- Strong growth to 2030 in solar deployment and increasing contribution from onshore wind.

FES 2019 – Consumer Evolution (CE)

- Slower decarbonisation overall (relative to other scenarios).
- Higher reliance on gas-fired generation, with modest increases in wind/solar generation.

Stability scenarios *(run for all FES cases)*

Status quo

- Modelled stability requirements for inertia and short-circuit level[1].
- Includes pathfinders 1, 2, and 3.
- Minimum action taken to meet requirements.
- Building the minimum amount of additional grid forming capacity (assumed to be synchronous condenser) to meet needs after redispatch actions.

Optimal

- Builds on status quo scenarios incl. long + short term markets.
- Explores what the ‘optimal’ (least cost) mix of stability providers would look like in GB.
- Grid-forming capability added to new providers deployed in future years (wind, storage, interconnection), assumed to be driven by short-term market revenues.
- Additional dedicated investment in the form of synchronous condensers where economically efficient in the scenarios.

Sensitivities *(run on optimal scenario for all FES cases)*

Grid forming capability

- Sensitises assumptions on converter grid forming capability deployment (+-50%).
- Designed to understand potential impact of uncertain deployment rate for grid forming providers.

Hurdle rates

- Sensitises hurdle rate assumptions for new synchronous condensers (dedicated).
- Designed to understand the impact of provider risk on potential future costs of stability management.

Notes: [1]For the constraints modelled, ESO technical analysis suggests procuring sufficient SCL capability also met needs for dynamic voltage support – however, in the future cases where specific dynamic voltage support needs may emerge.

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The scenarios and sensitivities considered indicates grid forming converters enabled by a day-ahead market could help to drive cost efficiencies

Scenario learnings

Stability scenarios *(run for all FES cases)*

Status quo

- Significant capability is already being procured by the pathfinders to ensure system security.
- There is limited need for additional provision to ensure stability requirements are met (assumes pathfinder 1 providers continue to be available to 2030).
- Reliance on balancing mechanism for redispatch, primarily to synchronise CCGTs to meet residual stability needs.

Optimal

- Significant cost savings due to the inception of grid forming technologies, offsetting the need to synchronise plant to provide stability to the system.
- Some limited room for new (profitable) investment, however long term procurement rounds under pathfinders secure for the bulk of the requirements/needs. This may change under scenarios with increased non-synchronous generation (e.g. FES21)

Sensitivities *(run on optimal scenario for all FES cases)*

Grid forming capability

- Cost differences aren't particularly large in general, but can be in specific regions.
- Strong locational signals are needed to ensure grid-forming Capex/Opex is only incurred by providers in the right locations.

Hurdle rates

- Due to level of long term investment, desirable to minimise cost of capital to providers to manage costs to consumers.
- Management of risk between consumers (ESO) and providers crucial in long-term market.

Key conclusions

- The system is expected to be **secure** under current arrangements (including pathfinders), but cost efficiencies can be improved.
- There is no single **technology** appropriate for solving all stability constraints/issues, future arrangements must facilitate the widest array of potential providers possible.
- There is a need for **locational** signals to ensure grid forming technologies are deployed in the right places (where they are most needed).
- Contractual terms for long-term should pay careful consideration that affect **risks** assumed by providers.

Modelling considerations/limitations

- Modelling based on **FES 2019**, expectations of future mix has evolved since publication.
- Modelling horizon limited to **2030**, needs expected to continue to grow post-period.
- Modelling relies on assumptions regarding **behavioural change** which is difficult to predict accurately.
- **Dynamic voltage** support not modelled explicitly[1], only 5 SCL regions modelled.

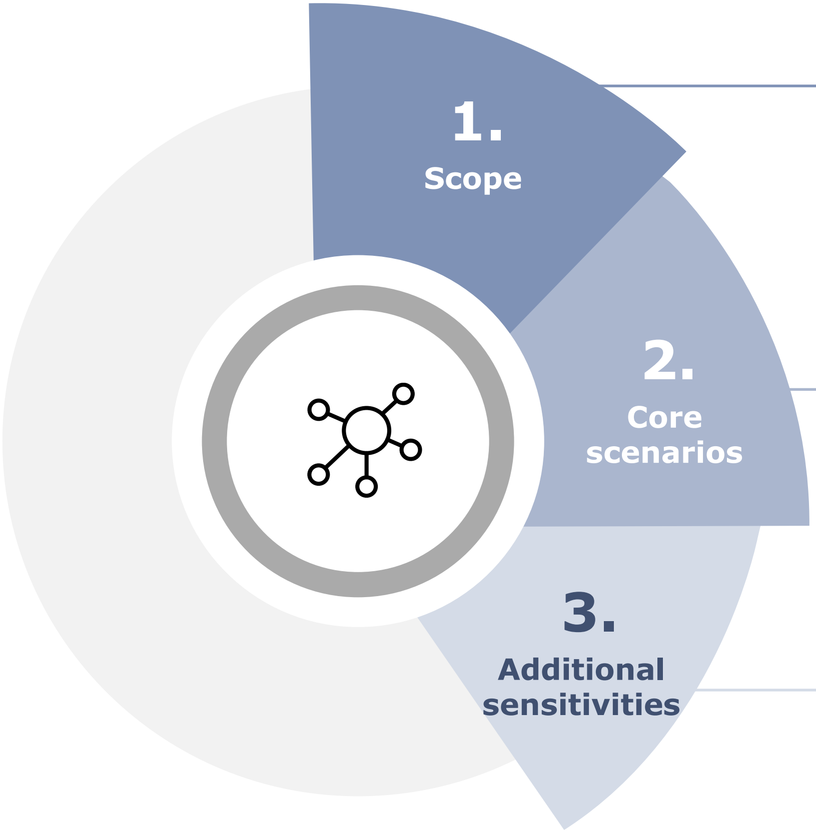
Notes: [1]For the constraints modelled, ESO technical analysis suggests procuring sufficient SCL capability also met needs for dynamic voltage support – however, in the future cases where specific dynamic voltage support needs may emerge.

STABILITY MARKET DESIGN – MODELLING ANNEX

2. Introduction

INTRODUCTION

AFRY has modelled stability constraints under ESO's FES scenarios to understand the nature of future requirements



- AFRY has modelled a number of scenarios using AFRY's BID3 power market model, the scenarios were based on **National Grid's Future Energy Scenarios (FES), 2019** edition: Two Degrees, Community Renewables, and Consumer Evolution.
- All scenarios were developed for two years (**2026, 2030**).

- **'Status quo'** scenarios: exploring implications of stability constraints under the status-quo – include pathfinders 1-3.
- **'Optimal'** scenarios: aiming to assess the impact of stability constraints by also accounting for technology evolution and economics, driven by the presence of a stability market – also includes pathfinders 1-3

- **Grid-forming capability dependency**: how sensitive are the findings to provider's capabilities?
- **Hurdle rates**: what is the impact of different hurdle rate assumptions on costs?

Notes: Modelled under FES 2019 scenarios to align with pathfinders analysis, Requirements under latest scenarios expected to be greater due to shifting views on future evolution of the electricity system (in particular towards high levels of non-synchronous generation)

INTRODUCTION

The modelling exercise in BID3 is based on 3 runs: the market-schedule run, the redispatch (inertia, SCL, boundaries), and the redispatch (only boundaries)

Modelled results and associated costs are subject to change with updated views. The current results use:

- *fuel and carbon price assumptions based on FES19,*
- *generation mix assumptions based on FES19,*
- *synchronous condenser costs based on assessment of Pathfinder 1 outcomes and assumptions from AFRY engineers.*

1 Data: alignment with ESO

Key data on stability constraints (requirements, plant capabilities, etc.) were provided by NG ESO

2 Data: processing

Stability constraints were integrated into FES scenarios in AFRY's BID3 power market model

3 BID3: Dispatch

The dispatch is the first modelling run, simulating market conditions at day-ahead

4 BID3: Re-dispatch

All Constraints

Both reserve constraints (inertia and SCL) and boundaries (i.e., thermal transmission constraints) represented in the model, plant positions are adjusted from the market schedule

5 BID3: Re-dispatch

Isolating impact of stability

Boundaries are accounted for, but inertia and SCL constraints are not. This allows us to identify the impact of boundaries alone on redispatch results: these can be netted from the outputs of the 'All Constraints' redispatch in order to isolate the impact of SCL and inertia

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INTRODUCTION

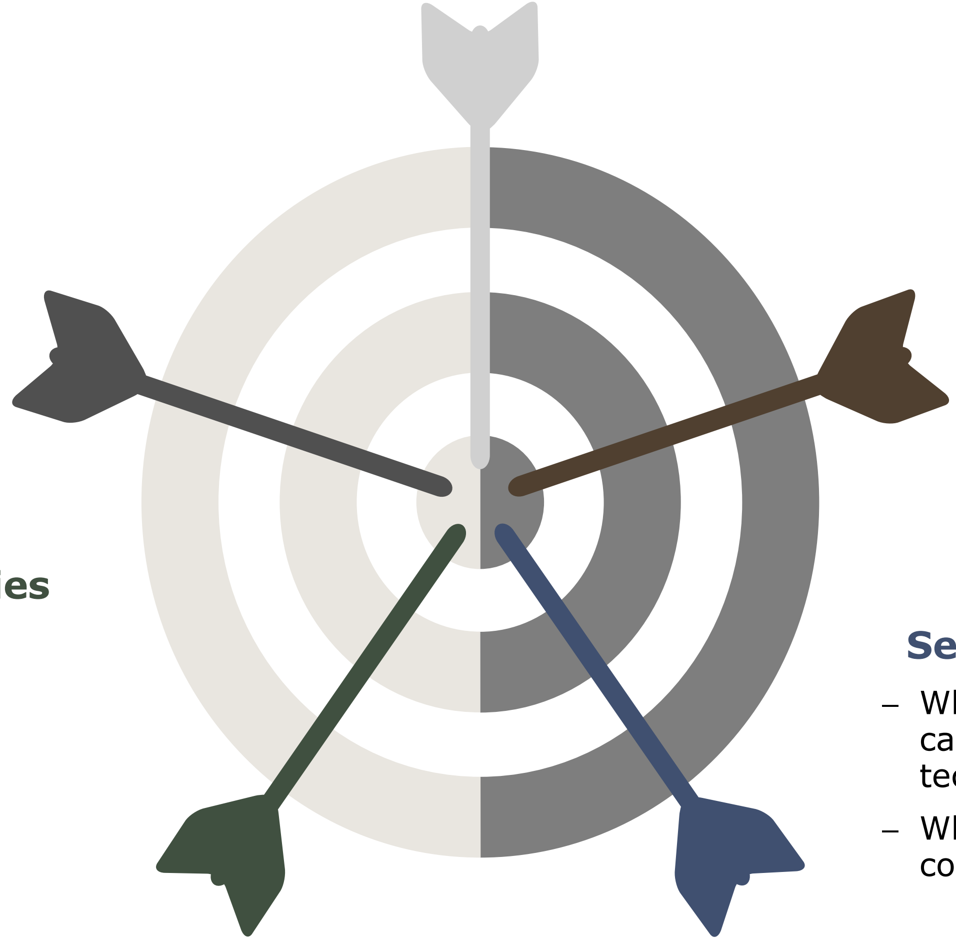
We aim to frame the challenges and scale of stability management, and assess the compatibility with design features

Nature of Requirements

- What is the nature of the shortfall in meeting stability requirements?
- What is the cost of managing the requirements?
- Are there patterns or dependencies in the requirements?

Technology dependencies

- What are the key technologies providing stability?
- What is the role of Pathfinder contracts?
- What is the potential impact from new grid-forming technologies?



New capability

- Is investment in new-build assets required?
- Where are new solutions needed?

Existing capability

- How significant is the role played by existing providers, and in particular by the Stability Pathfinders?

Sensitising Assumptions

- What is the impact of alternative stability capability from Grid-forming technologies?
- What is the potential benefit of a lower cost-of-capital?

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MODELLING ANNEX

3. Scene setting & case for change

Key changes from running the system today

- The modelling work relied on key assumptions supplied by NG ESO, with regards to the Inertia and SCL requirement.
- The minimum Inertia level assumed to determine the requirements in our modelling is **90GVA.s + inertia associated with the largest infeed**
- This minimum requirement stems from a number of assumptions which are important to acknowledge. Inertia management is dependent on a set of key variables relating to the following relationship:

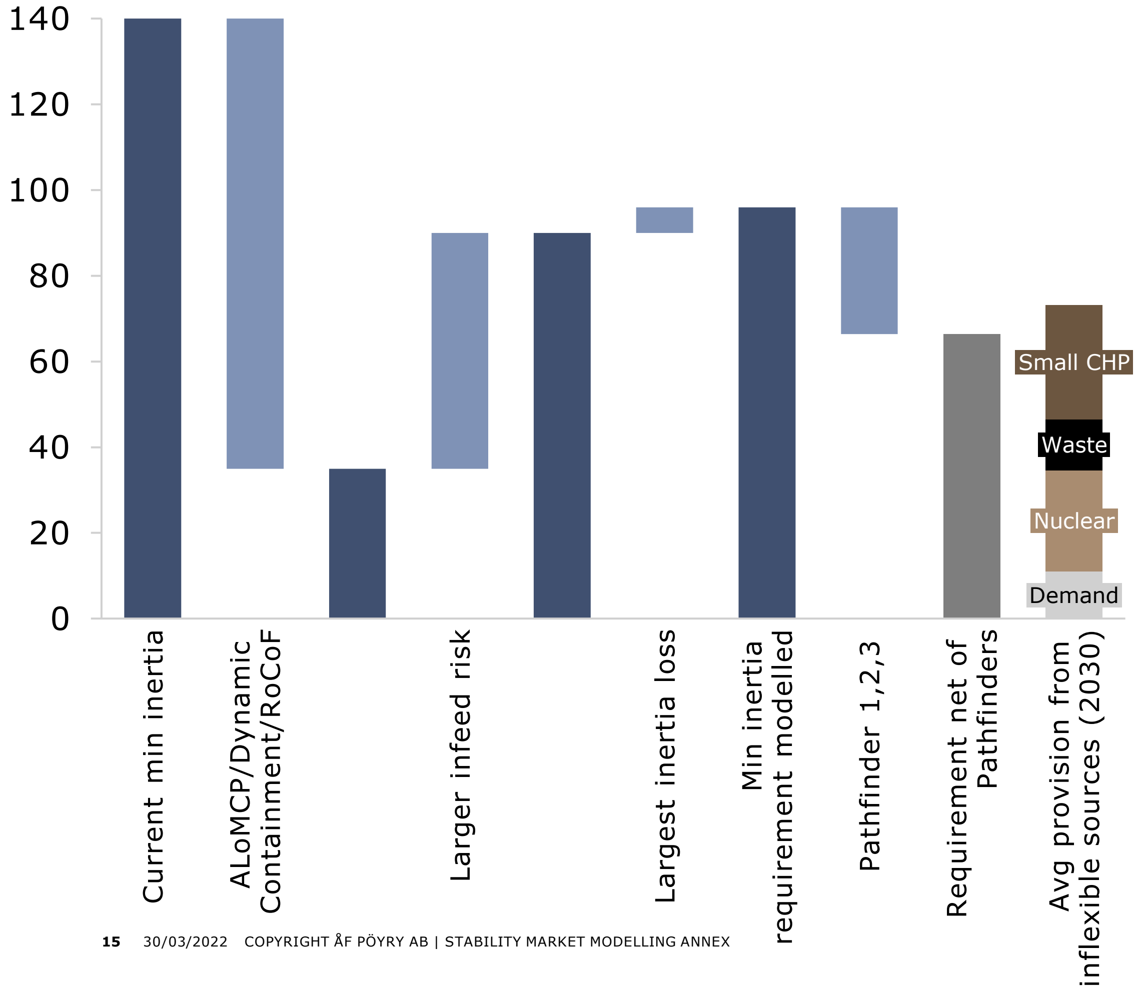
$$RoCoF\ (Hz.s^{-1}) = \frac{Frequency\ (Hz)}{2} . \frac{Largest\ Infeed\ Risk\ (GW)}{Inertia\ (GW.s)}$$

- The RoCoF limit is assumed to be at 0.5Hz/s (up from current policy of 0.125Hz/s)

SCENE SETTING & CASE FOR CHANGE – KEY ASSUMPTIONS REGARDING INERTIA

Competing drivers influence future inertia requirements in GB, the net effect is a reduction in minimum inertia requirement levels from today

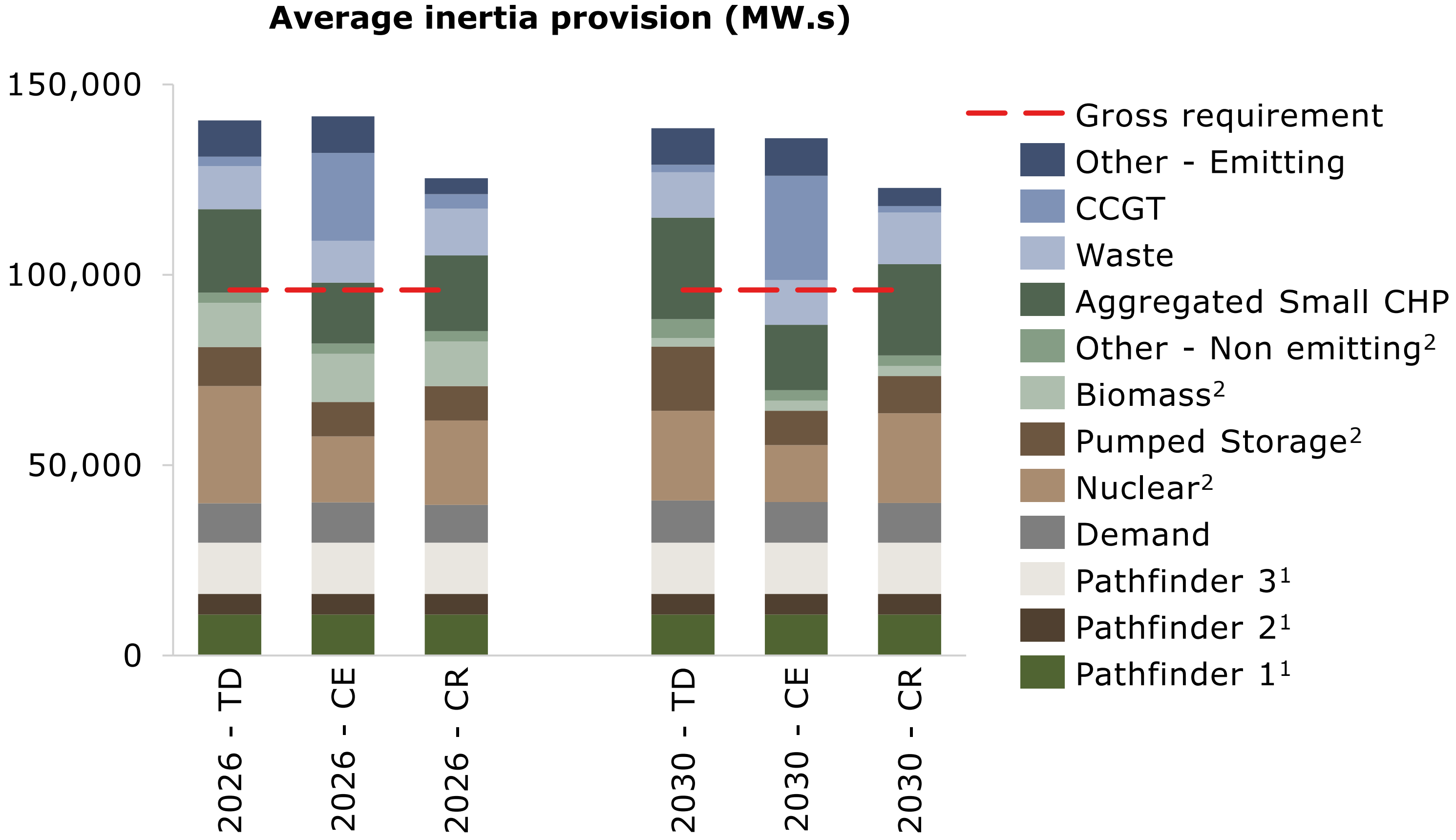
IMPACT OF NG PROGRAMS ON REQUIRED INERTIA (GVA.S)



- NGESO current policy is to have a minimum of 140GVA.s of inertia.
- Inertia limits depends on the maximum infeed size running at any given time and the RoCoF limit.
  - Accelerated Loss of Mains Change Programme (ALoMCP) will reduce the minimum inertia requirement by making small generation more robust to changes in frequency. Combined with reform to frequency response products, a higher RoCoF limit (0.5HZ/s) results in reduced inertia limits.
  - The decrease from the higher RoCoF limit is partially offset by a larger infeed size
- Stability Pathfinders run by NGESO have led grid forming solutions winning long-term inertia provision contracts. We have assumed that a total of 33.5GVA.s is provided and supplied from Pathfinder 1, 2 and 3. This supply is over one-third of the minimum inertia requirement.
- Inflexible providers of inertia can meet the remaining inertia gap in our modelling – but may not always be running/available due to planned/unplanned outages.

INERTIA PROVISION IN THE FES 2019 SCENARIOS

The FES 2019 scenarios[1] show sufficient inertia provision to meet the requirement at the market-schedule stage…

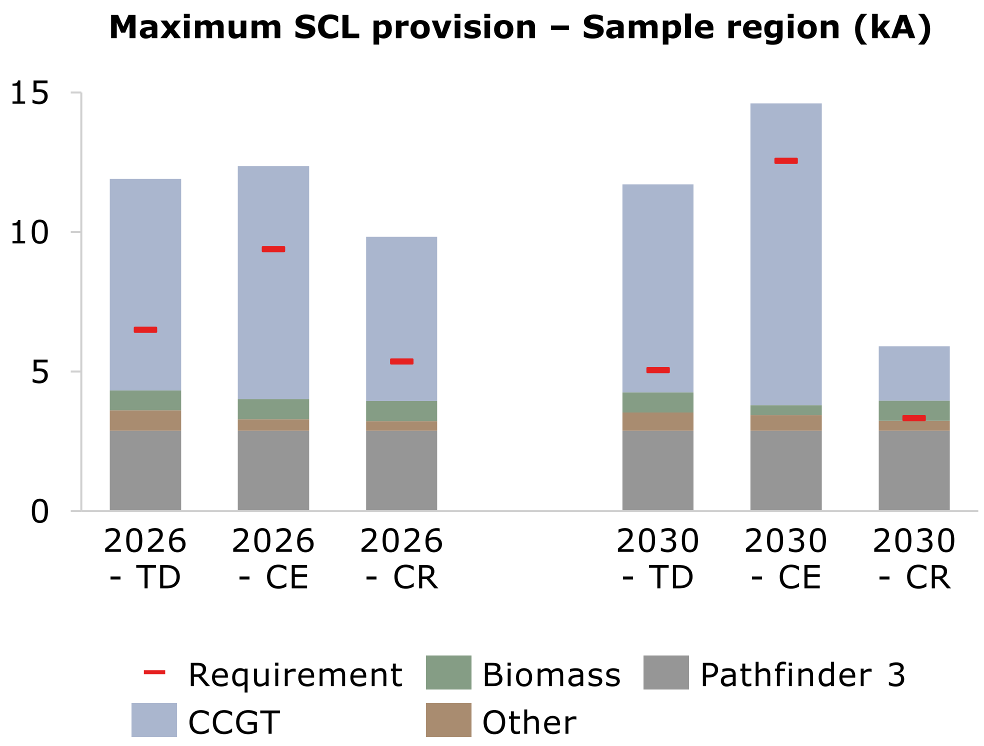


- The synchronous-condenser (assumed) capacity procured via the Stability Pathfinders 1, 2 and 3 is added to the FES 2019 scenarios.
- Overall, there is enough inertia provision on the system, year round, to meet the system requirement (90GVA.s + largest infeed).
  - On average (see chart), there would still be need for CCGTs/gas CHP in order to reach the desired level of inertia provision.
- The Stability Pathfinder capacity plays an important role, in the absence of this capability, additional redispatch to meet inertia constraints would be required and system security could be threatened.
- Synchronous generators with low marginal costs (or other revenue streams) provide inertia that can be considered "baseload" such as CHP, waste, nuclear, biomass.

1. With the addition of the capacity procured in Stability Pathfinders 1, 2 & 3
2. Acts as baseload provision, PS accessible through existing contracts, note that we are running with average availability not taking into account specific nuclear outage patterns

SCL CAPABILITY IN THE FES 2019 SCENARIOS

…however, whilst there is sufficient Short Circuit Levels capability in most regions providers are not always expected to be running



- Short Circuit Levels (SCL) are locational, not all providers in GB will be able to contribute to all regional SCL needs. As part of this project we have modelled 5 key regions.
- SCL requirements are determined by a number of factors, however they are increasingly being driven by large volumes of non-synchronous generation employing grid-following converter technologies, which can become unstable with insufficient SCL.
- Many traditional providers of SCL (such as CCGTs) are being pushed increasingly out of merit, creating a deficit at times when low marginal cost intermittent generation is dominating the system.
- In these instances CCGTs must be synchronised to ensure the local system remains sufficiently stable.
- *The data shown in the charts excludes baseload providers of SCL. In this sense, the maximum SCL requirement and the SCL capabilities shown here represent only units that are redispatched to meet needs + pathfinders*.

Note: Red dashes represent the maximum SCL requirement (excluding SCL baseload providers)

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MODELLING ANNEX

4. Status quo scenarios

STATUS QUO SCENARIOS – KEY ASSUMPTIONS FOR INERTIA AND SCL CONSTRAINT MODELLING

The ‘Status quo’ scenario represents no change from todays arrangements, new capability is only built if system security is threatened

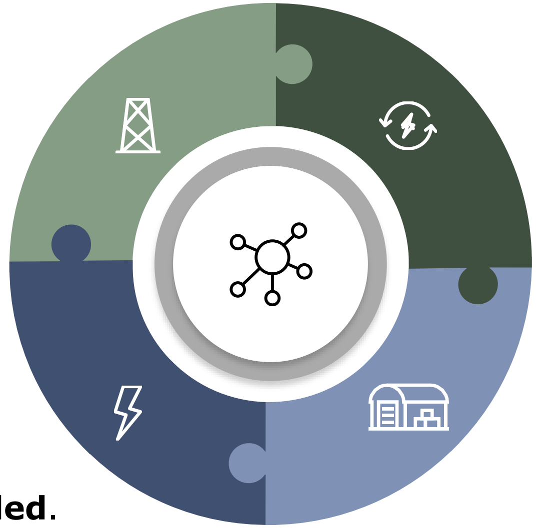
Stability Pathfinders

- **Synchronous condensers with flywheels** are added into the FES 2019 scenarios, to reflect the capacity procured via Stability Pathfinders 1, 2 and 3.
- Given their location, capacities from Pathfinders 1 and 2 can contribute to **inertia**, but not to the SCL constraints considered in this study due to location.
- However, capacities considered for Pathfinder 3 can contribute to both **inertia** and **SCL** modelled constraints.

Plants’ SCL capabilities

Plant SCL capabilities are based on data provided by NG ESO[1].

- Only **transmission-connected** (Tx) plants are **included**.
- The following groups of plants are included implicitly in stability demand figures:
  - Baseload providers of SCL, and Small Embedded Generators (SEG);
  - plants that are **electrically too far** away from the regions of interest.
- We assume that there are no **GFC technologies** deployed in the **absence of incentives**, except for few batteries included in data received by NG ESO.



Plants’ inertia capabilities (H values)

- Inertia H values for power plants are based on the “**Case study technologies**” slide pack by AFRY where possible.
- They are based on the **technology-average** H values provided by **ESO** for the remaining technologies.

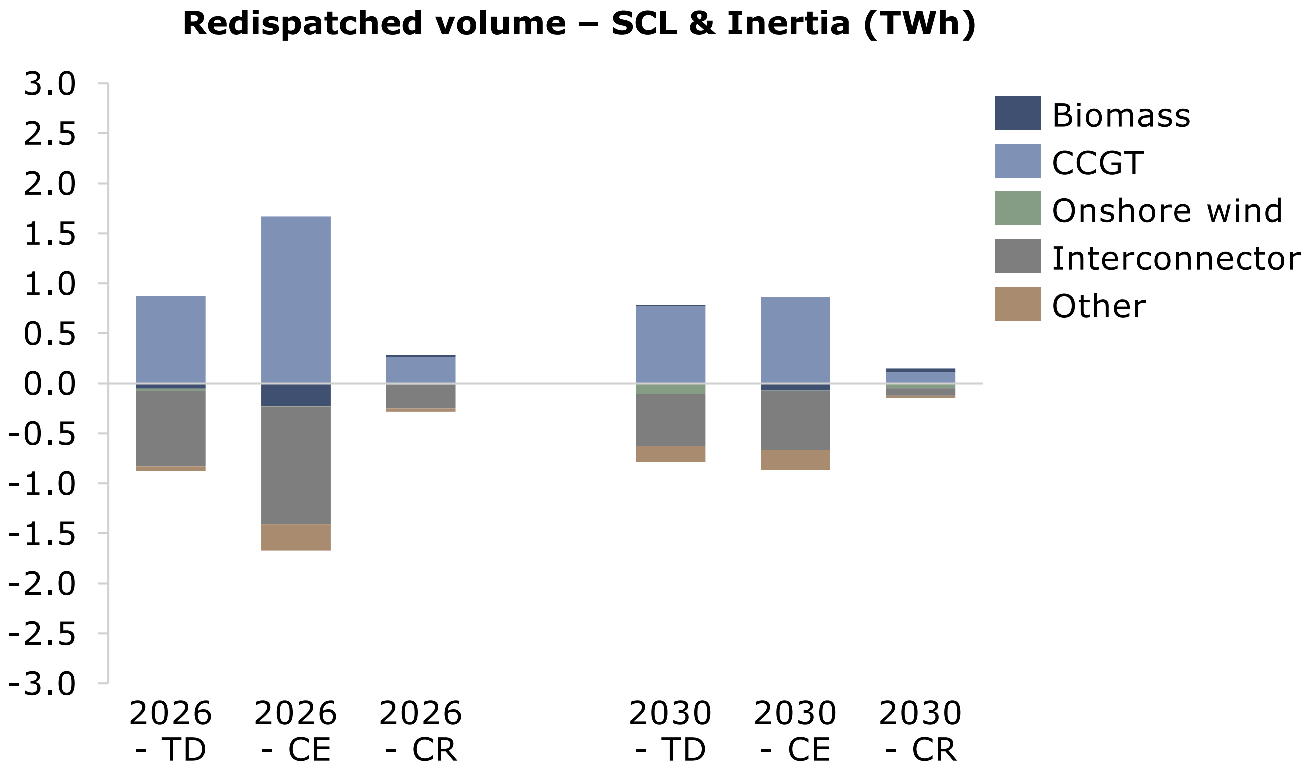
Electricity-demand capability

- Electricity demand can provide **inertia**.
- **H=0.3s** is assumed as an H value for electricity-demand. This refers to the **gross demand**, and not to demand net of embedded generation.

Notes: [1]Except for SCL capability of synchronous condensers, which is based on the “Case study technologies” slide pack by AFRY.

MODELLING RESULTS - REDISPATCH VOLUMES

Inertia and SCL constraints have little impact on RES output, primarily adjusting interconnector positions to make room for CCGTs on the system

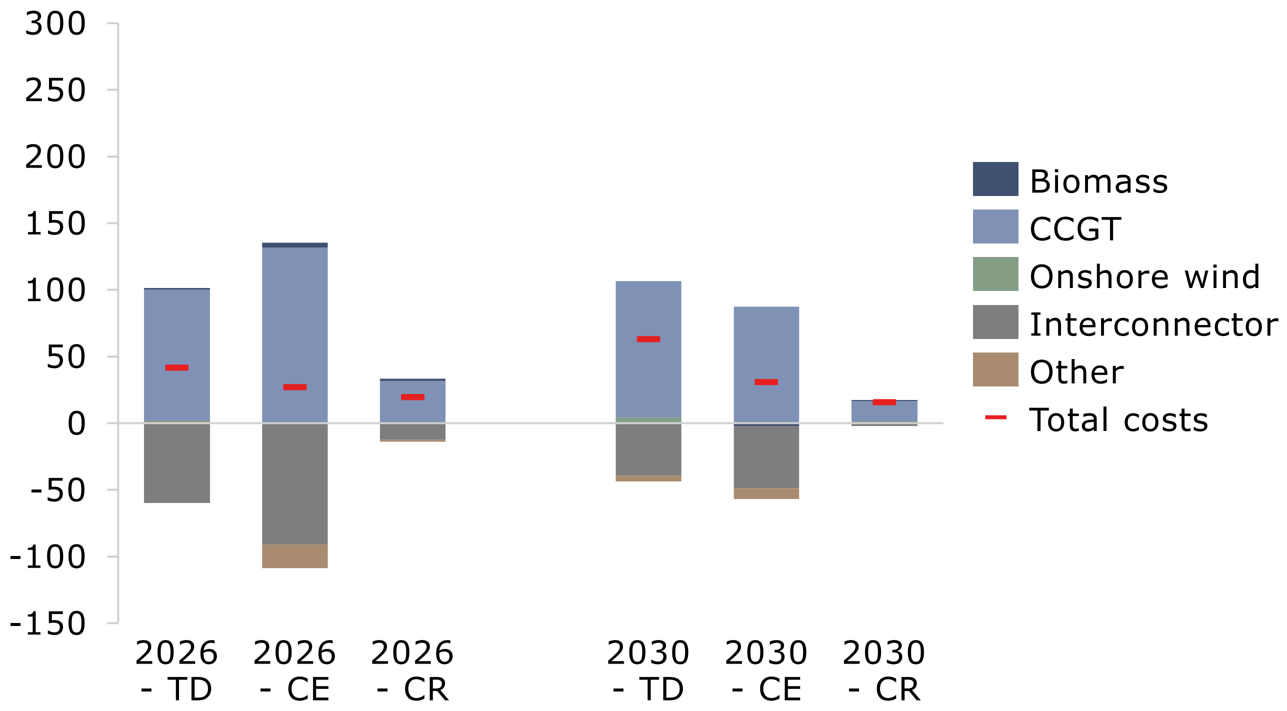


- By netting the 'Only Boundaries' run results from the 'All Constraints' run results, we can isolate impact of inertia and SCL constraints (stability constraints) on the system.
- Typically constraints are managed through synchronising CCGTs, which are able to provide both inertia and SCL.
- Interconnector imports are offset to make 'room' on the system for CCGTs to synchronise.
- It is not necessary to curtail large volumes of wind to meet stability constraints, which can be managed more economically through changing interconnector positions.

MODELLING RESULTS - REDISPATCH COSTS

The cost of meeting the inertia and SCL requirements is driven by an increase in spend on synchronising CCGTs

Redispatch costs – SCL + Inertia (£m, real 2019)

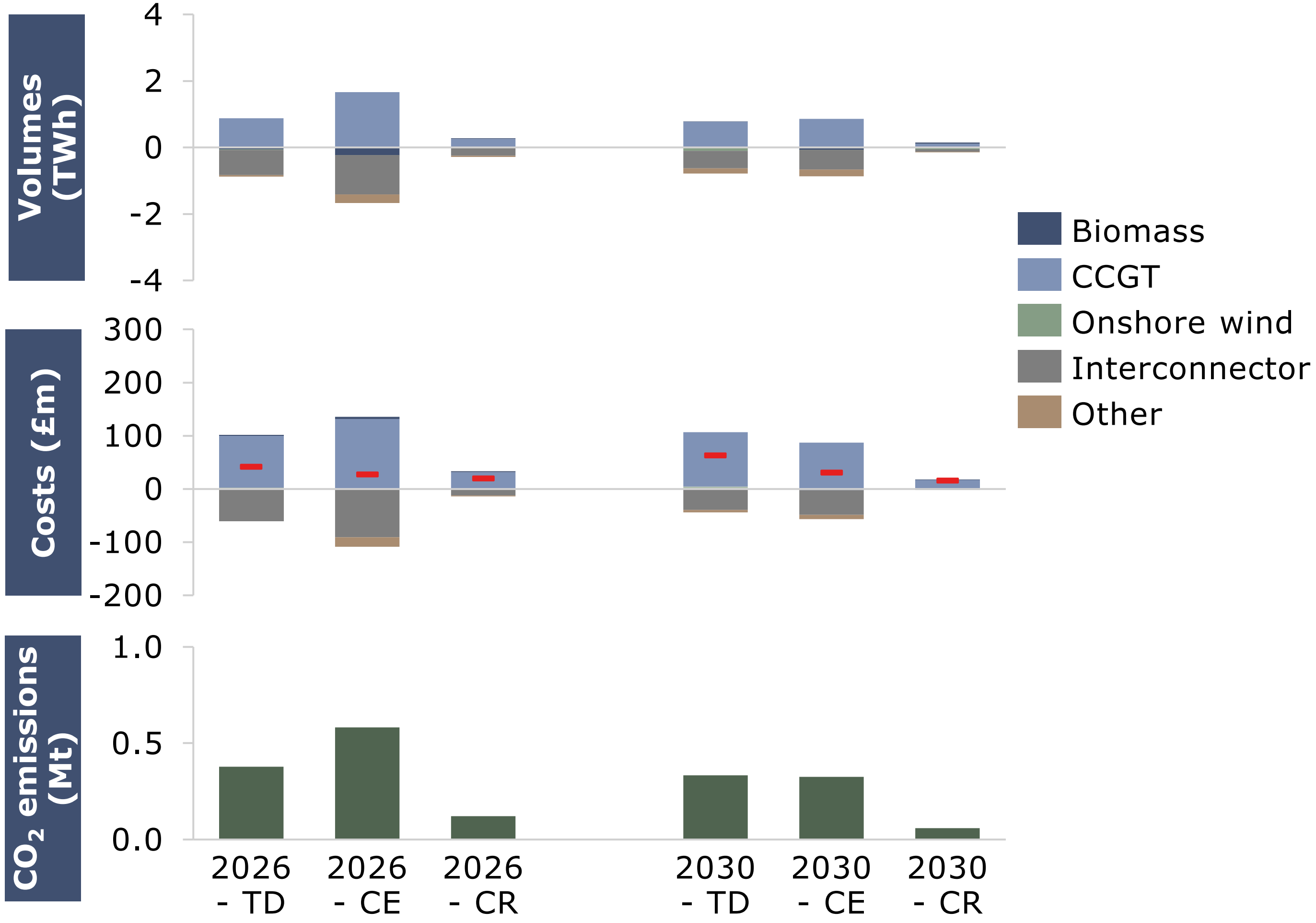


- Unlike with transmission constraints, the impact on wind (both offshore and onshore) and other RES sources is minimal as the redispatch volumes of these technologies remain mostly unchanged in the presence of inertia and SCL constraints.
- CCGTs are synchronised to provide stability to the system when required and in the absence of any other incentives are the key tool used to increase provision of stability on the system.
- Net total payments are between £15m and £63m depending on scenario and year.
  - *It should be noted we are not modelling all regional constraints as part of this project, incl. dynamic voltage support, therefore figures may underestimate actual total cost of management of stability constraints. Furthermore, analysis is based on FES19 scenarios.*

Note: Red dashes represent the total cost of the redispatch actions.

MODELLING RESULTS – STATUS QUO SCENARIOS

The current route to access stability services is through the BM, requiring active MW instructions which can be costly and carbon intensive

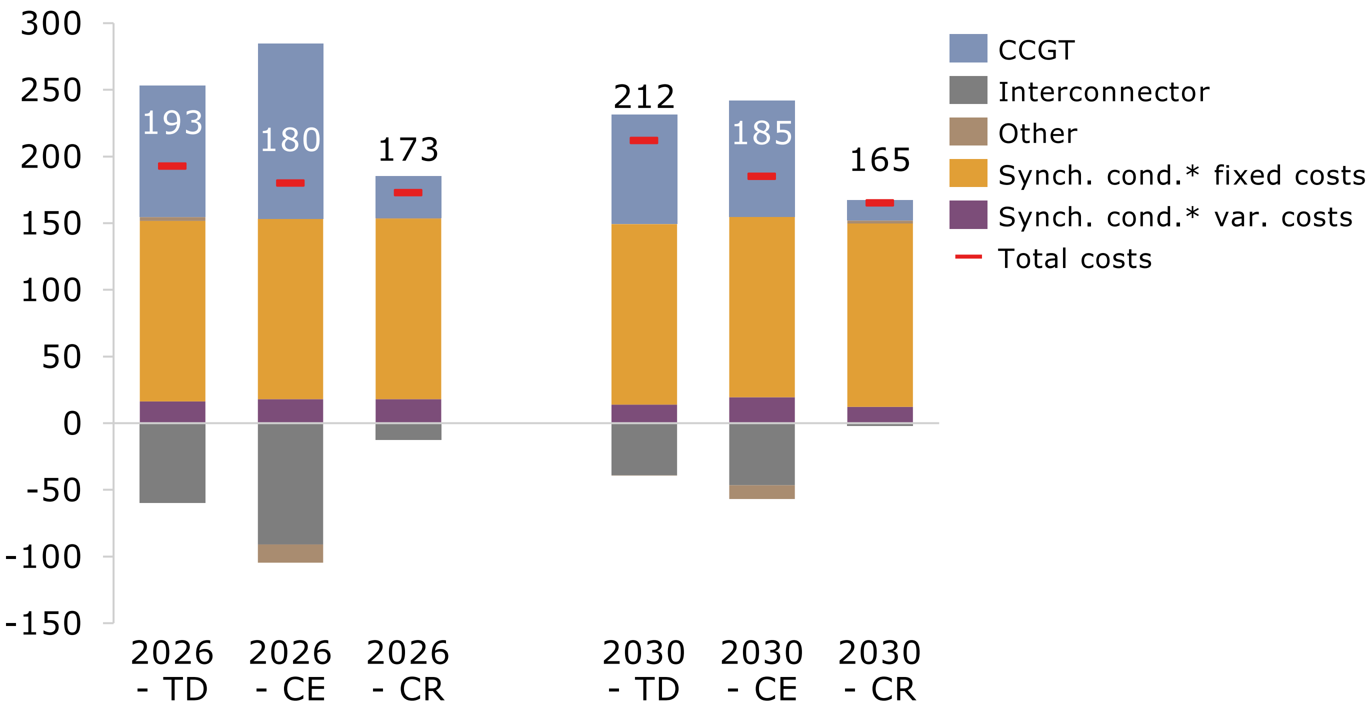


- Under the current market arrangements, any under-procurement of stability services (at market schedule) needs to be sourced via the Balancing Mechanism.
- This process results in an increase of output from out-of-merit CCGTs in order to procure sufficient stability services. Which puts upwards pressure on both costs and CO_2 emissions.
- Apart from interconnector positions and CCGTs, other technologies remain relatively unaffected in the scenarios considered.

MODELLING RESULTS – SYSTEM COSTS OF MEETING STABILITY SERVICES

The total system costs for meeting stability requirements is determined by a combination of redispatch actions and investments[1]

Total system costs – SCL + Inertia (£m, real 2019)



- The total cost of meeting the inertia and SCL requirements depends on the redispatch actions, as well as on the fixed and variable costs of dedicated providers of such services (assumed synchronous condensers in this instance).
- The dedicated providers procured via Pathfinders 1, 2 & 3 have materialised (or are assumed to materialise) as a direct result of the Pathfinder processes. Their costs are directly related to meeting the system's stability needs.
  - If these capacities were not considered, significant additional costs would be incurred for the redispatch of other assets.
  - Further analysis is done in the next section ('Optimal' scenarios) to determine the potential benefits of bringing new investments to the system, leading to potential savings in terms of lower redispatch costs.
- The chart shows the annualised value of new investments for dedicated providers.

Notes: [1]Synchronous condenser costs refer to both the Stability Pathfinders 1, 2 and 3, and to the additional capacity required beyond these assumed investments.
Note: Red dashes represent the total cost of meeting the stability requirements.

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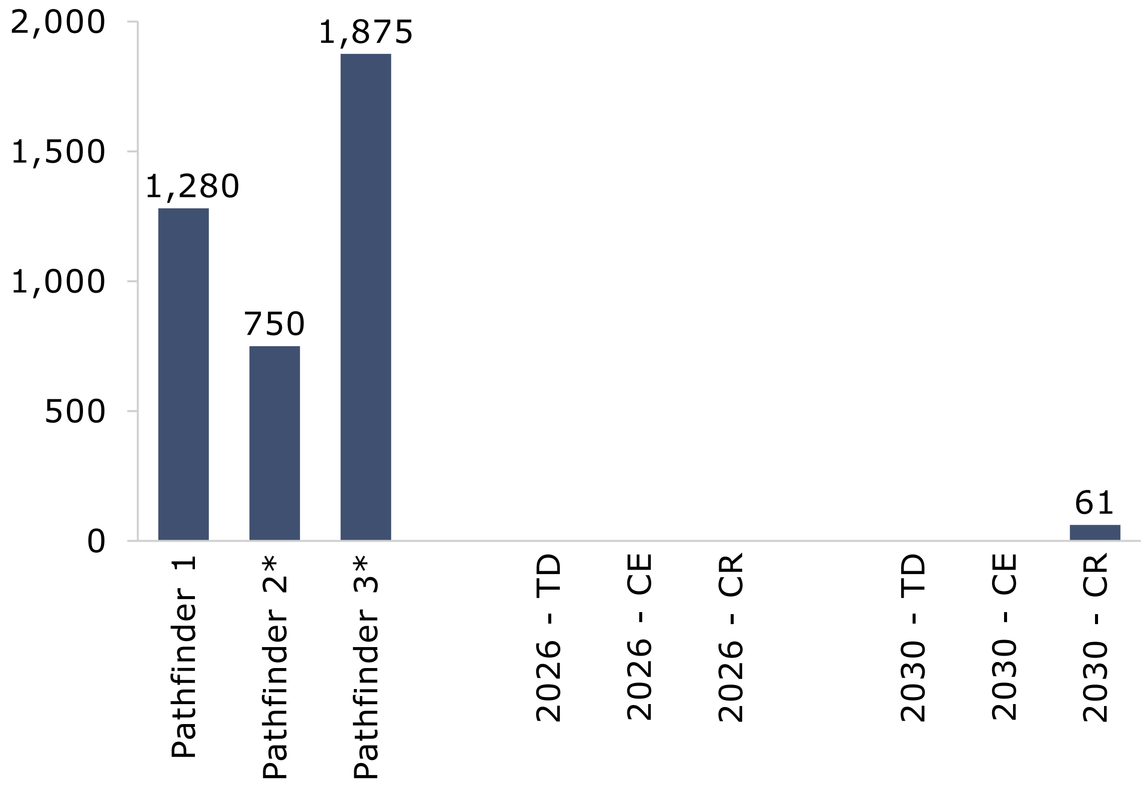
MODELLING RESULTS – DEDICATED PROVIDER CAPACITY IN STATUS QUO SCENARIO

To meet the SCL requirements in every scenario, we have added ~60MVA of synchronous condenser capacity by 2030, on top of the Pathfinders

Additional synchronous condenser capacity (MVA)



- The volumes expected to be procured via the Stability Pathfinders 1, 2[1] & 3[1] mean there is little need for additional capacity to meet the maximum stability requirements.
  - Capacity from Pathfinders 1 and 2 cannot provide SCL in the regions we have modelled due to their locations, limiting their SCL contribution to the 5 regions of interest we are currently modelling.
  - The capacity procured in Pathfinder 3 is divided among the 5 regions modelled for SCL.
- Given their assumed location, the (assumed) synchronous-condenser capacity procured in Pathfinder 3 has the direct consequence of increasing the inertia and SCL provision in the system. That is, these capacity additions relax stability constraints further.
- Nevertheless, despite these capacity additions, there are still periods where, at a market-schedule stage, the SCL provision is below the system requirement.

Note: [1]The capacity for Stability Pathfinder 2 & 3 is assumed based on information from NG ESO.

MODELLING ANNEX

5. Market driven: ‘Optimal’ scenarios

'OPTIMAL' SCENARIOS – KEY ASSUMPTIONS FOR INERTIA AND SCL CONSTRAINT MODELLING

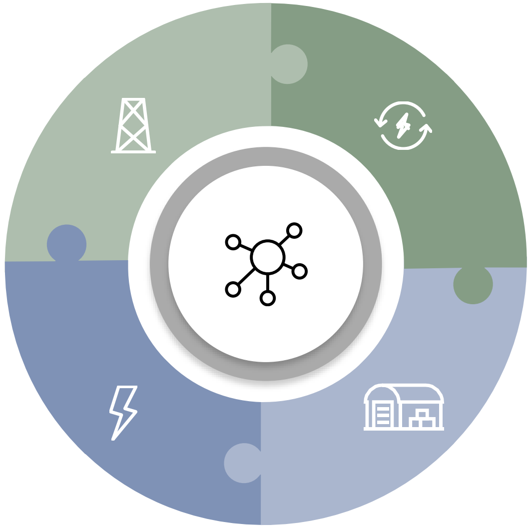
Below are the key assumptions for inertia and SCL capability in the 'Optimal' scenarios, which are key to understand the modelling outputs

Stability Pathfinders

- Same assumptions as in the 'Status quo' scenarios.

Plants' inertia capabilities (H values)

- Same as in 'Status quo' scenarios for non-GFC technologies.
- However, on top of the former, we assume that the following **GFC technology** can provide inertia:
  - new batteries: built from 2023 onward.



Plants' SCL capabilities

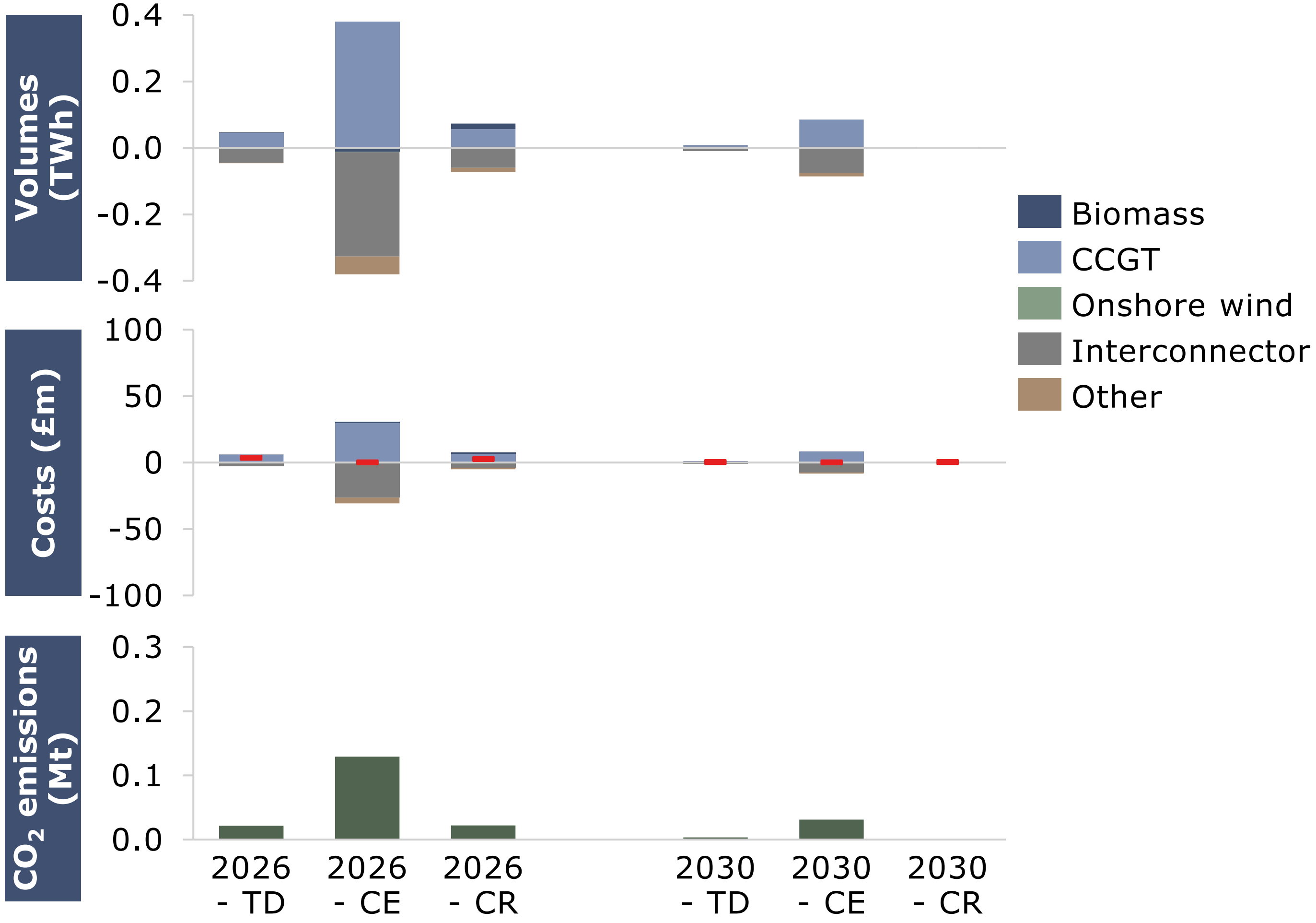
- Same assumptions as in the 'Status quo' scenarios.
- However, on top of the former, we assume that the following **GFC technologies** can provide SCL:
  - new batteries: commissioning from 2023 onward,
  - new onshore wind: commissioning from 2025 onward,
  - new offshore wind: commissioning from 2027 onward, and
  - new interconnectors with grid-forming capabilities.
- Note: representative SCL **effectiveness factors** are identified and accounted for when specifying each plant's capabilities.

Electricity-demand capability

- Same as in 'Status quo' scenarios.

OPTIMAL' SCENARIOS – MODELLING RESULTS

Due to the SCL provision coming from GFC technologies and to the additional synchronous condenser capacity[1], redispatch costs are low



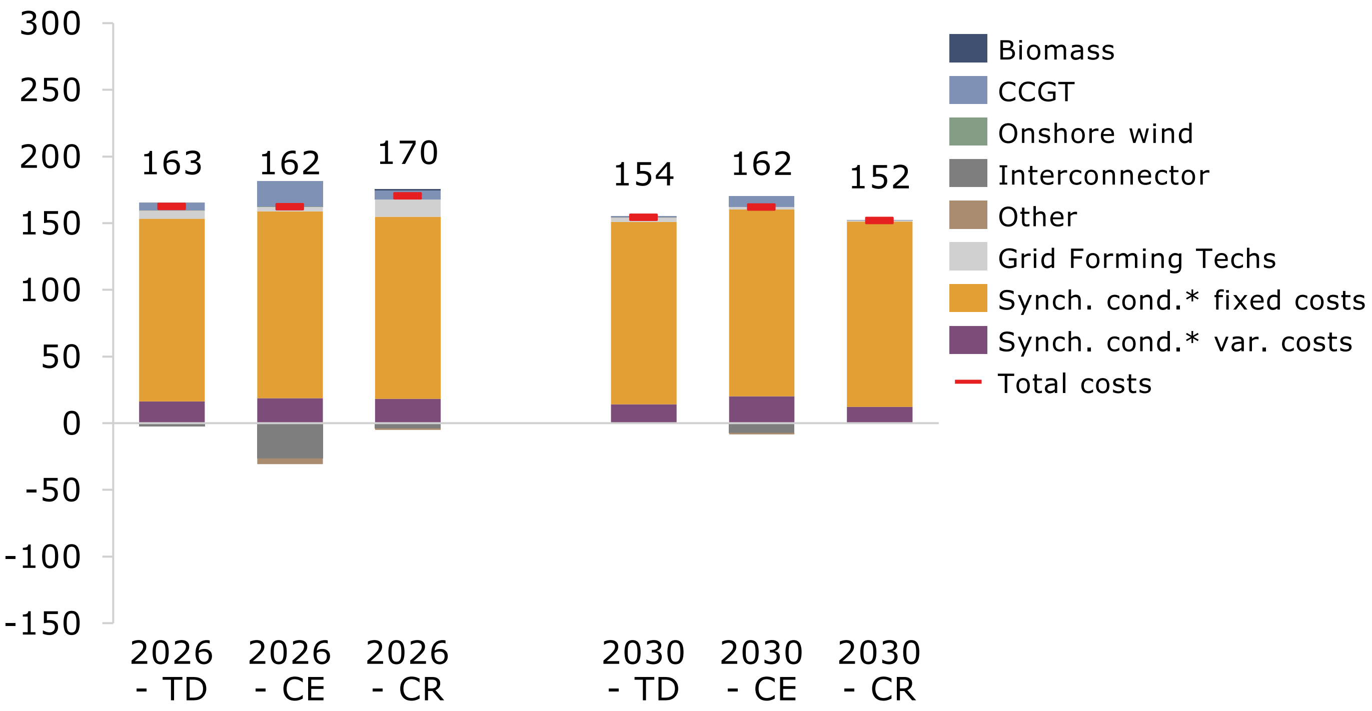
- In the 'Optimal' scenarios we accounted for technology evolution, in particular for the SCL capability of GFC technologies.
  - We have assumed that a ST market arrangement would be in place in order to enable the deployment of grid-forming converter connected providers.
- We have also added extra synchronous condenser capacity*, where beneficial, further lowering system redispatch costs.
  - We have assumed that some form of LT market would be in place in order to procure additional dedicated providers' capacity going forward.
- The outcome of this assessment is that the need for redispatch actions is reduced, both in terms of volume, cost and CO_2 emissions.

Notes: [1]Additional synchronous condenser capacity was added on top of the Stability Pathfinders, were economical, as presented in the following pages.

MODELLING RESULTS – SYSTEM'S COSTS FOR OPTIMAL SCENARIOS

The fixed costs of investments brought online via the Pathfinders[1] represent the largest share of system costs to guarantee the system's stability

Total system costs – SCL + Inertia (£m, real 2019)



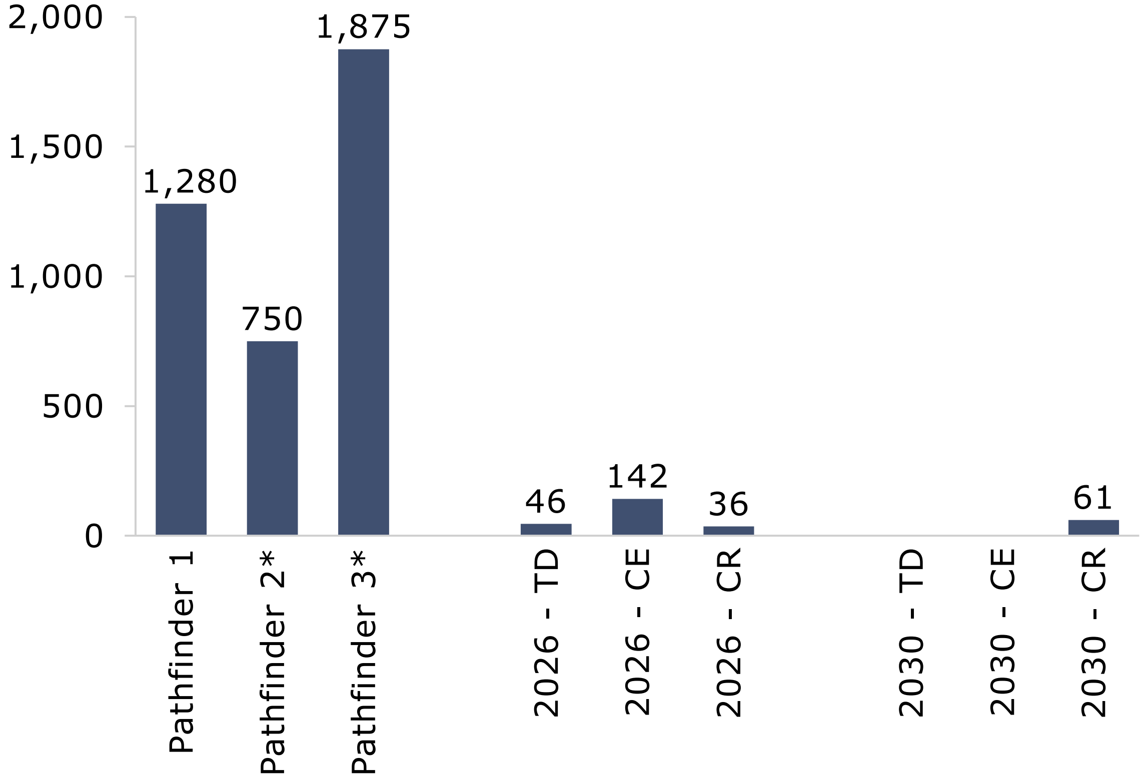
- As redispatch costs decrease with the addition of grid-forming technologies, the total system cost of procuring enough stability services is driven mainly by Pathfinders' investment costs (and corresponding payments made under long term contracts).
- However, grid forming technologies provide a substantial contribution to overall constraint management.
- *Note that for existing pathfinders rolling off contracts, we have assumed they are able to continue to recover investment costs at the same rate as their existing contracts, however this is unlikely to be the case in the presence of a competitive market at the end of their contract durations.*
- *The chart shows the annualised value of new investments for dedicated providers.*

Notes: [1]Synchronous condenser costs refer to both the Stability Pathfinders 1, 2 and 3, and to the (modest) additional capacity built on top of them (see in the following pages).

MODELLING RESULTS – ECONOMICS OF DEDICATED PROVIDERS

Looking at the economics of synchronous condensers suggests that there is limited need/benefit for deployment to 2030

Additional synchronous-condenser capacity (MVA) needed to minimise system costs



- The amount of additional synchronous condenser capacity required to minimise system costs is limited (and focussed on 2026, requiring no additional capacity by 2030).
- The magnitude of this extra capacity and its SCL provision is relatively small, if we compare it to the SCL provision which is assumed to be procured in the Stability Pathfinder 3:

MODELLING ANNEX

6. Scenario comparisons

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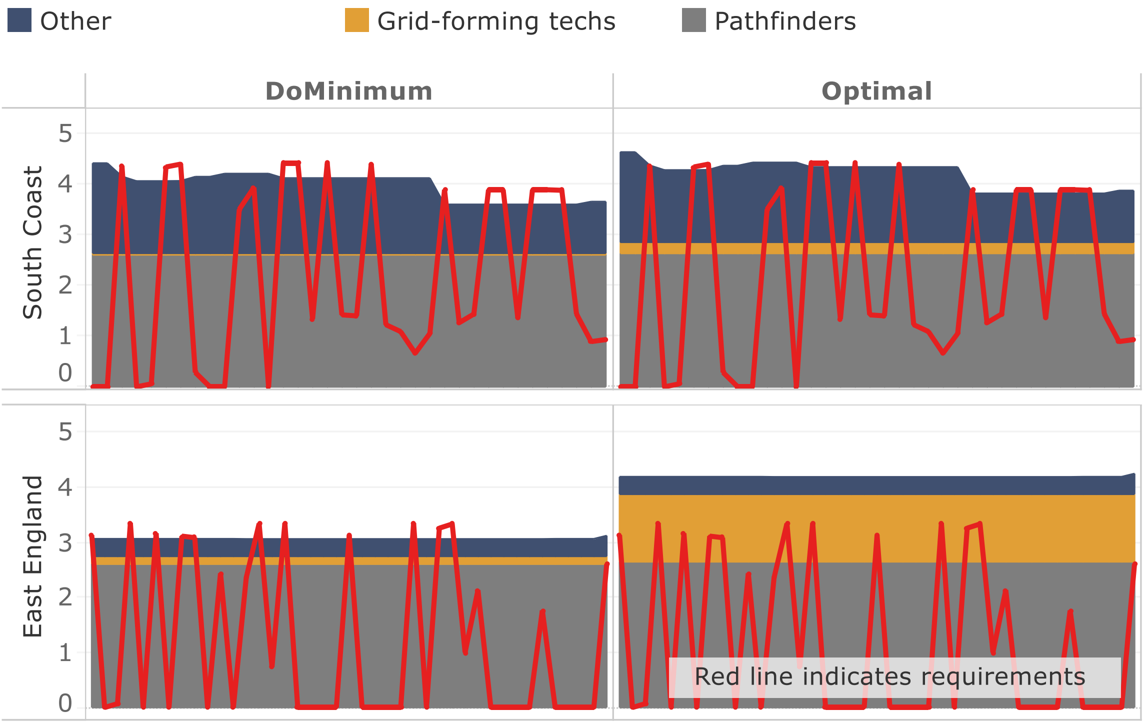
MODELLING RESULTS – OPTIMAL SCENARIOS VS STATUS QUO

In addition to the capacity procured via the Pathfinders, grid-forming converter connected technologies can contribute to solving future challenges

SCL provision (kA) at market schedule: Consumer Evolution – 2030[1,2]



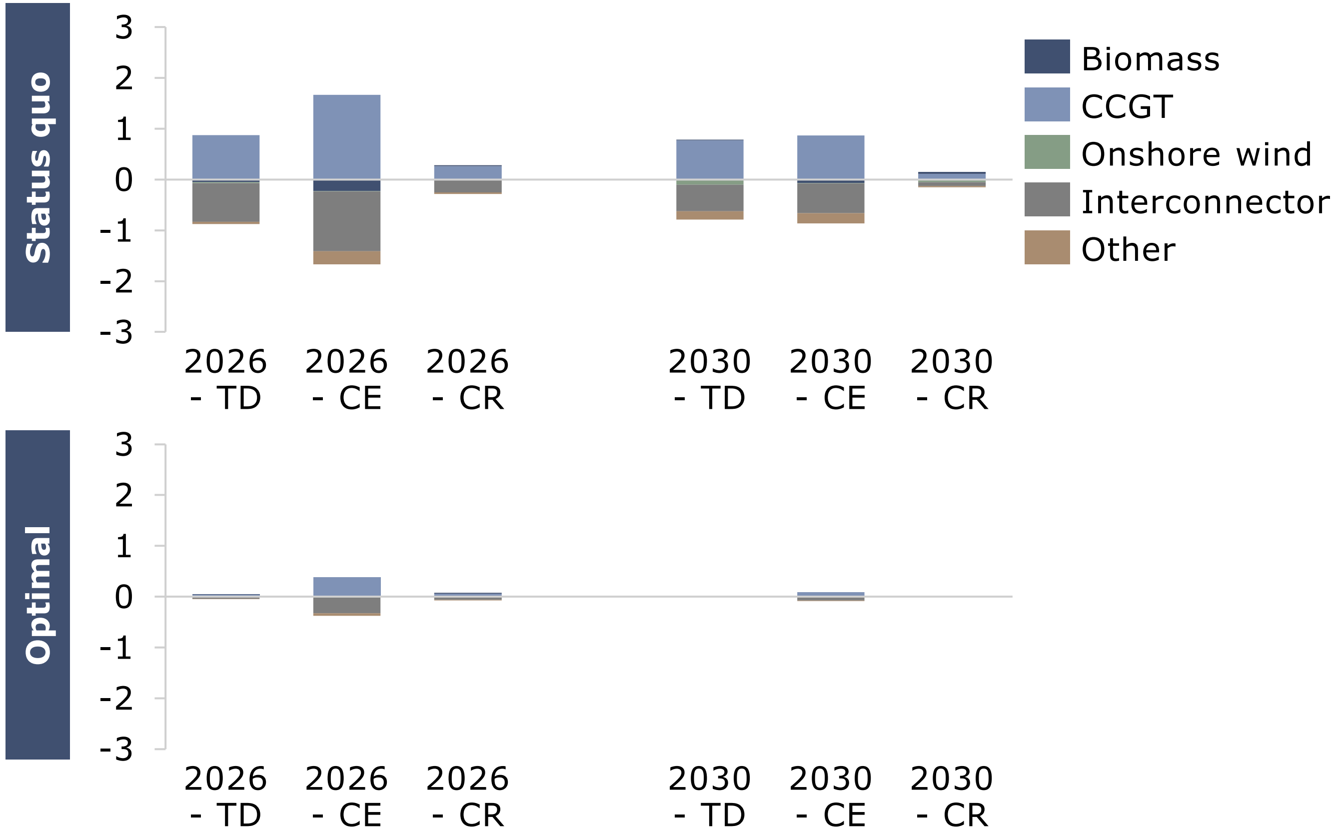
- Incentivising grid-forming based technologies to provide SCL on the system can result in a significant increase of the SCL on the system ahead of any balancing mechanism actions (if instructed to operate in grid-forming mode).
- Such an increase in SCL provision implies that certain periods which had shortfall of stability products in the 'Status quo' scenarios, would no longer experience such shortfalls in the 'Optimal' scenarios.
  - This highlights the importance of a market design that can enable and access the provisions from such technologies.
  - *The small provision by grid-forming technologies in the Status quo scenario corresponds to some batteries for which NG ESO provided SCL assumptions.*
- A limitation of the modelling is that the inclusion of grid-forming technologies would in reality not only increase the SCL provision, but it would also have the effect of reducing the system requirement.

1. Only Consumer Evolution scenario is shown as an example, however similar messages can be extrapolated to other scenarios and other SCL regions
2. Baseload providers of SCL are netted off from requirements and provision

MODELLING RESULTS – OPTIMAL SCENARIOS VS STATUS QUO

There is an overall reduction of redispatch volumes, however the Consumer Evolution scenario still sees around 0.4TWh of redispatch volumes from CCGTs in 2026

Redispatch volume – SCL & Inertia (TWh)



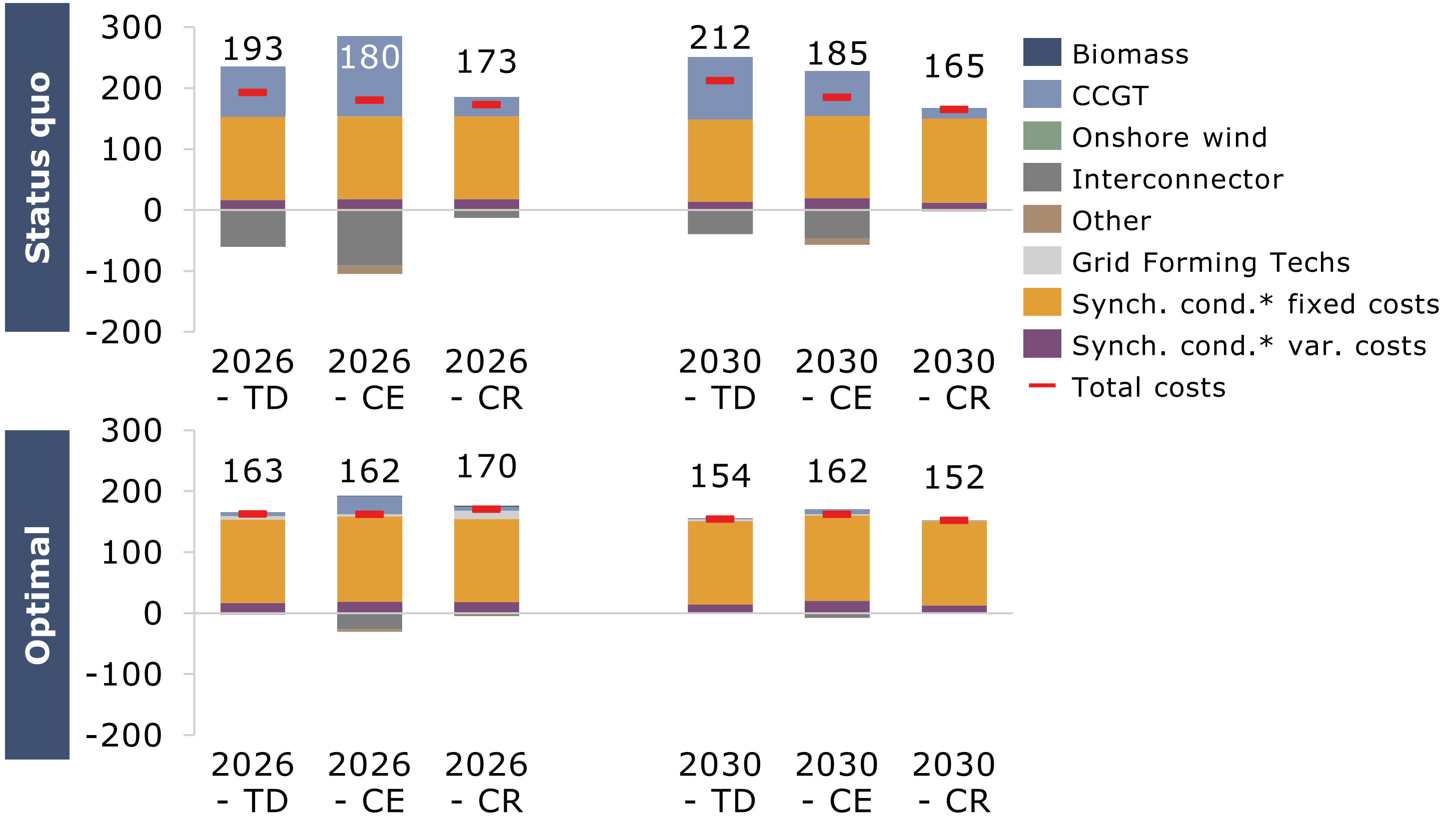
- As the contributions from grid-forming technologies increase the SCL available, fewer MW actions are required in order to procure sufficient stability product availability.
  - A reduced amount of periods where redispatch actions are required, result in an overall decrease of redispatch volumes, when compared to the ‘Status quo’ scenario.
- *Two Degrees* and *Community Renewables* scenarios have minor redispatch volumes as the SCL provision at market schedule (including SCL from grid forming technologies instructed through a stability market) is almost always enough to maintain the system’s stability needs.

Note that we are referring to ‘redispatch’ as actions that can be taken by the ESO in balancing timeframes, in reality we expect these providers to participate in a short term market arrangement preventing the need for MW instruction through the BM

MODELLING RESULTS – OPTIMAL SCENARIOS VS STATUS QUO

System costs decrease in most scenarios and years in line with the decrease in CCGT redispatch volumes

Total system costs – SCL & Inertia (£m, real 2019)



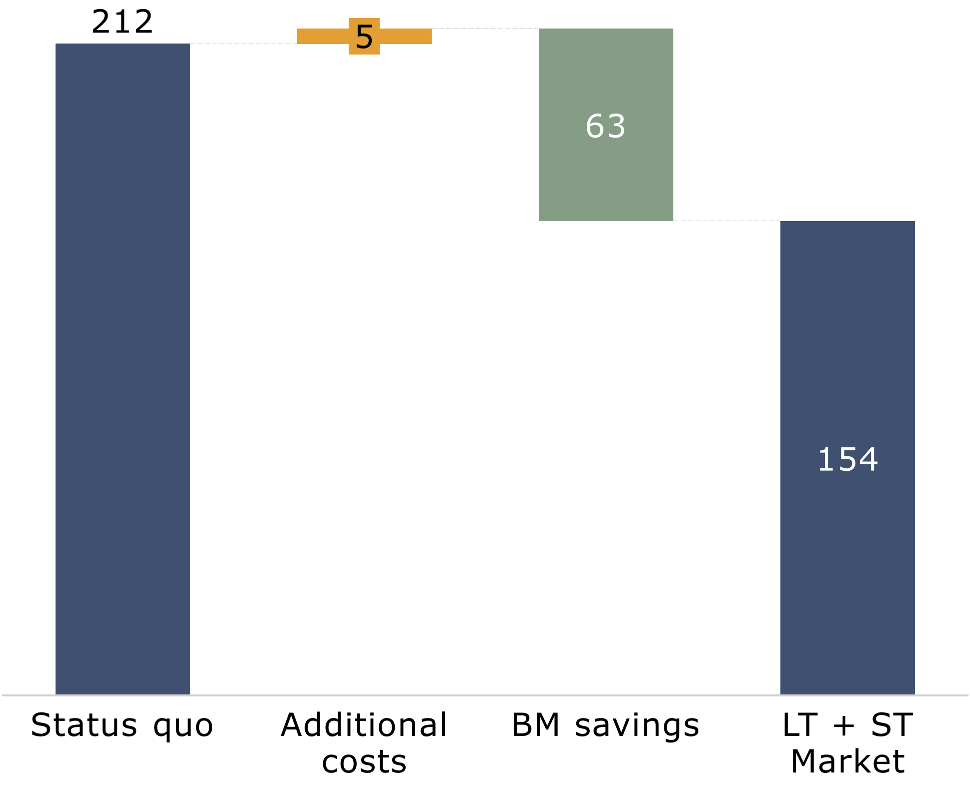
- As the contributions from grid-forming technologies increase the SCL provision, fewer actions to maintain stability are required.
- Lower redispatch volumes result in lower redispatch costs incurred to maintain the system's stability needs.
  - For the Two Degrees scenario, this represents savings of £30m in 2026 and £58m in 2030.
- The 'Optimal' scenarios also incurs costs paid to grid-forming technologies in order to reflect the incentive that such technologies have to invest in this type of technology and to operate in grid-forming mode (market value based rather than cost based).
- Regardless, the total system costs our scenarios display savings when providing a route-to-market for grid-forming technologies relative to continued use of the balancing mechanism.

Note that we are referring to 'redispatch' as actions that can be taken by the ESO in balancing timeframes, in reality we expect these providers to participate in a short term market arrangement preventing the need for MW instruction through the BM

MODELLING RESULTS – OPTIMAL SCENARIOS VS STATUS QUO

System costs decrease in most scenarios as costly redispatch actions are offset by cheaper providers, especially grid forming technologies

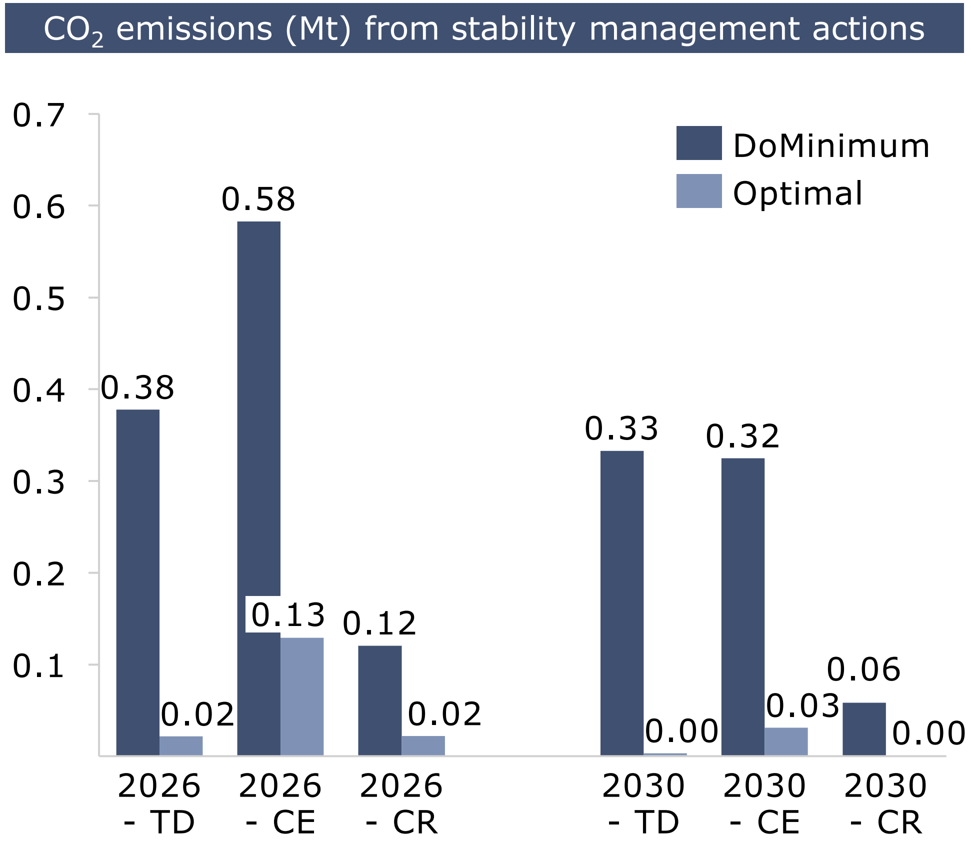
Total system costs TD scenario 2030 – SCL & Inertia (£m, real 2019)



- The introduction of a short-term market (shown in the graph under 'LT+ST markets') will further reduce costs (~£58m net in 2030, Two Degrees scenario).
- Additional costs to grid-forming technologies through marketplaces are ~£5m to unlock these benefits.
- The benefits are driven by a reduction in total re-dispatch actions (primarily of CCGTs, whose re-dispatch volume from stability management in 2030 decreases to close to zero with the addition of a ST market.
- This is a result of the additional stability provision which makes the system more resilient in meeting stability requirements.
- Due to the relatively large volumes procured under pathfinder 1, 2, and 3, there is limited additional benefits from deploying more dedicated long-term assets. The majority of additional benefits therefore accrue due to the facilitation of grid forming technologies in short-term arrangements.
  - *Note: analysis based on FES19 which includes lower levels of non-synchronous generation than FES21. In updated scenarios, there may be additional need for long-term investment to ensure system security and therefore a combination of long-term and short-term markets should be considered.*

MODELLING RESULTS – OPTIMAL SCENARIOS VS STATUS QUO

Carbon emissions decrease significantly due to the reduction in the redispatched CCGTs



- Due to the SCL provision increase from grid-forming technologies, less carbon-emitting generation needs to be redispatched.
- This has the direct consequence of substantially reducing the CO_2 emissions from redispatch actions
- On average a reduction of 90% is seen across scenarios and years.

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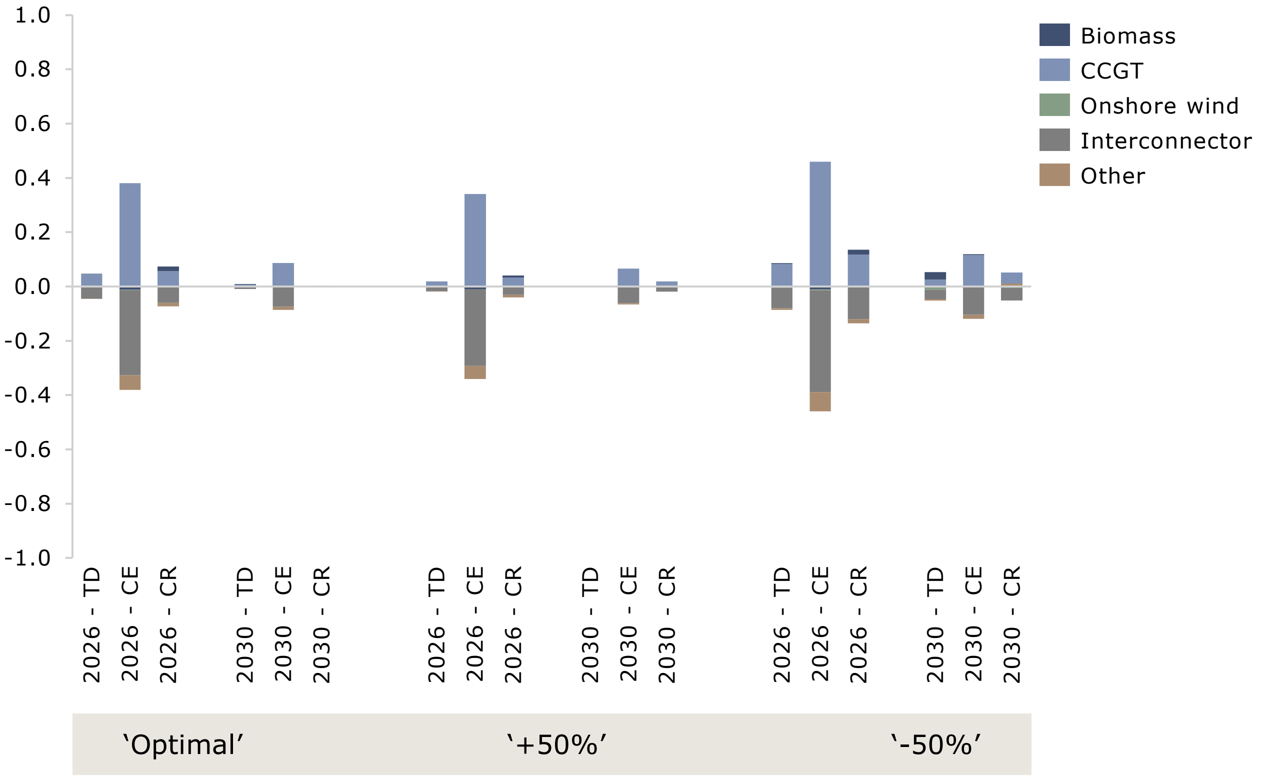
MODELLING ANNEX

7. Testing assumptions: Grid-forming dependency

MODELLING RESULTS – SENSITIVITY

In order to test the sensitivity of results to the SCL capabilities of new Grid Forming plants, two cases were explored: +50% and -50% capability

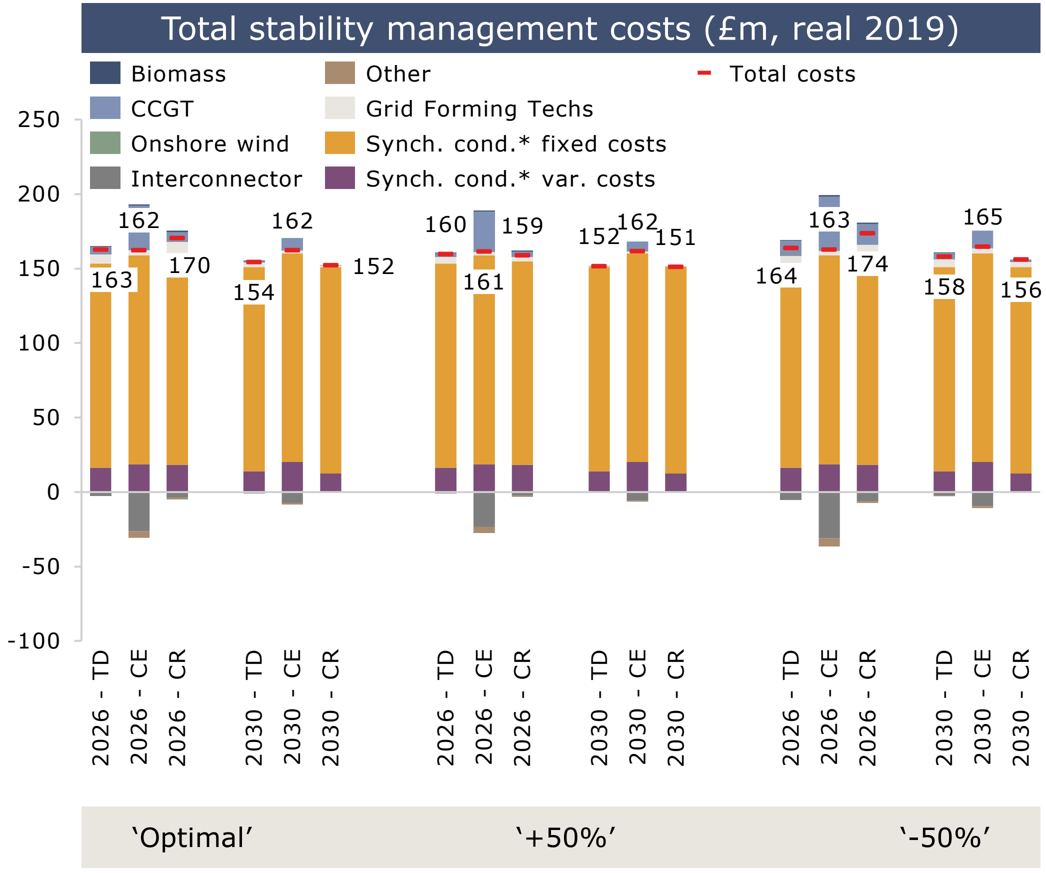
Redispatch volumes – SCL & Inertia (TWh)

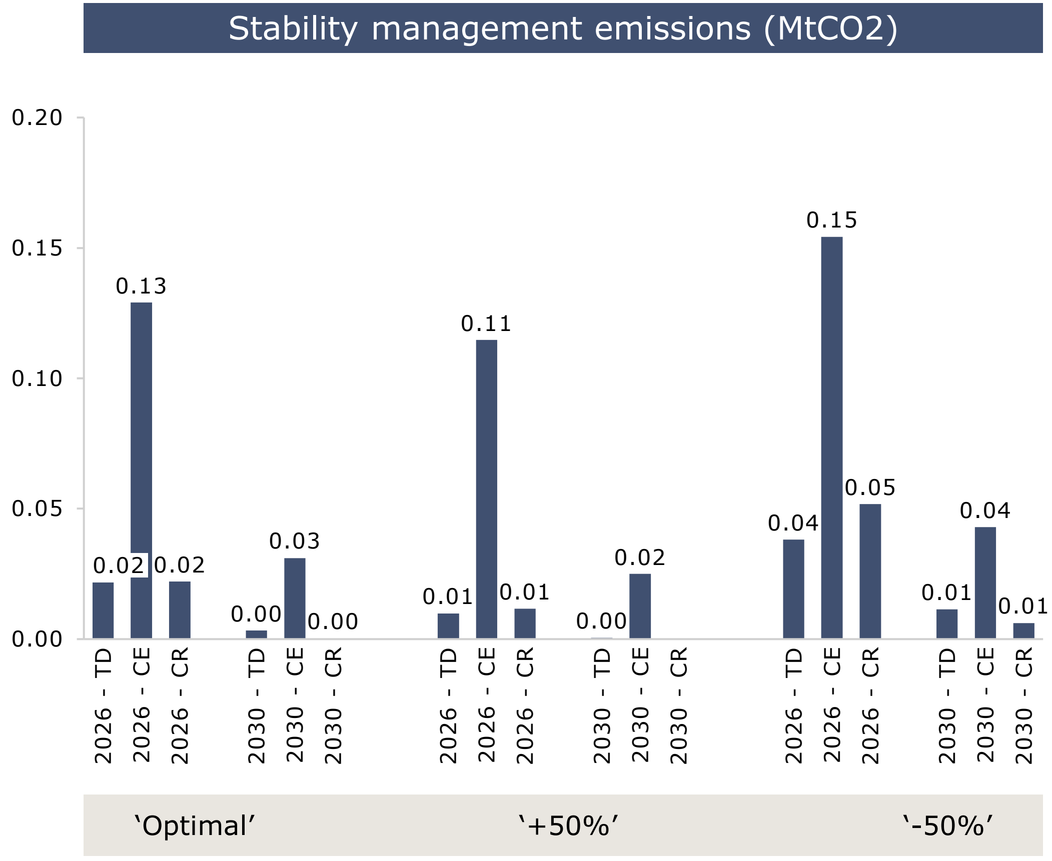


- We have increased and decreased grid forming converter connected technology by +-50% in the two sensitivities run on:
  - new batteries (commissioning from 2023 onward), new onshore wind (commissioning from 2025 onward), new offshore wind (commissioning from 2027 onward), and new interconnectors with grid-forming capabilities.
- Moreover, scenarios in these two sensitivities were optimised and extra synchronous condenser capacity was added (on top of the synchronous condenser capacity in the 'Status quo' scenarios), wherever beneficial for the system in terms of lowering the system costs.
- The outcome is, redispatch volumes are lower, in absolute terms, in the '+50%' sensitivity, however, the reduction is generally small as converter connected technologies are not necessarily in the right place to meet future stability requirements.

MODELLING RESULTS – SENSITIVITY

Changes in redispatch volumes are reflected in lower costs and lower carbon emissions for the +50% sensitivity, and increased costs/carbon emissions in the -50% sensitivity





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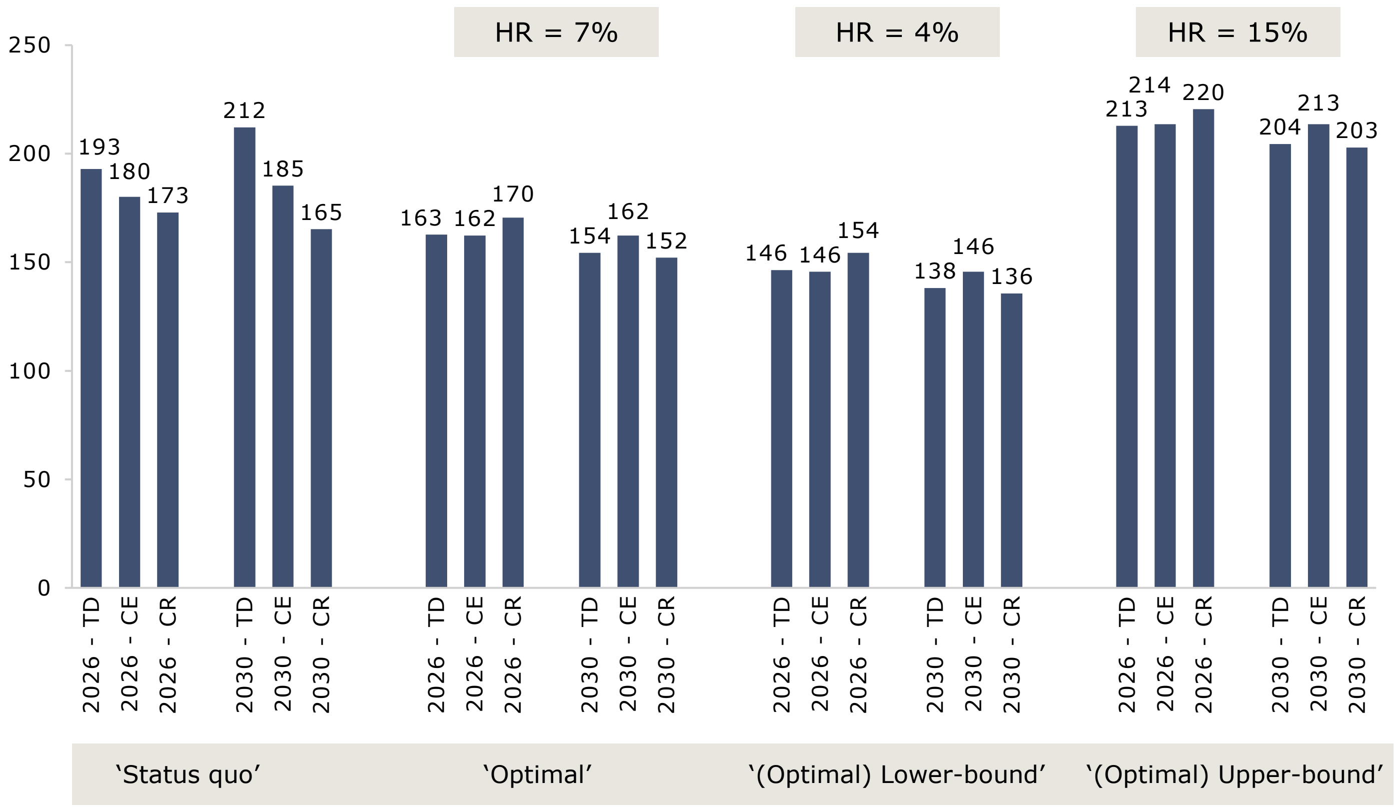
MODELLING ANNEX

8. Testing assumptions: Cost of capital

MODELLING RESULTS – SENSITIVITY

Sensitivities on the 'Optimal' scenarios indicates a lower hurdle rate could reduce costs, minimising cost of capital should be an objective of the long-term market

Total stability management costs (£m, real 2019)



- We tested the impact of different hurdle rates on the 'Optimal' scenarios (where we have assumed synchronous condenser investment are characterised by a hurdle rate of 7%[1]).
- A reduction in hurdle rate from 7% to 4% reduces total costs by roughly £15m-£20m/y, conversely an increase to 15% increases costs by ~£50m/y.
- The objective of the long term market should be to minimise risk to providers, whilst not exposing consumers to risks (underwritten by ESO) that are not best borne by them.
- Some crucial elements of a long term market that could help to mitigate risk include:
  - Longer duration contracts (ideally matching as closely as possible the lifetime of the asset), lowering exposure to uncontracted residual value that participants must take a view on.
  - Opportunity to manage long term variable cost risk (e.g. variable input costs such as electricity for synch comps) through contractual framework, such as some form of utilisation costs.

[1]Pre-tax, unlevered, real hurdle

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