October 2025

Strategic Case for Tidal Range

ARUP

NESO
National Energy
System Operator

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Executive Summary

Introduction

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Introduction

This study aims to establish the potential impact on Great Britain's future energy system, and total cost to consumers, of deploying tidal range generating assets in a range of scenarios. It follows the Strategic Outline Case (SOC) approach in HM Treasury's Green Book Five-Case model[1]. The focus of the Economic Case is an assessment of what impact there might be on GB consumers of each of the different scenarios, including no tidal range deployment at all. Different delivery models and subsidy mechanisms have also been considered to explore the potential delivery requirements of the studied scenarios.

The study compares three scenarios of varying total capacity, location and deployment timescales of tidal range generation assets around the UK coastline, as well as a counterfactual scenario where there is no tidal range energy generation. The NESO Future Energy Scenario 2024 Hydrogen Evolution pathway[2] has been used as the basis of the electricity supply and demand profile to 2050, and the network upgrades planned in Holistic Network Design[3], and Beyond 2030[4] have been incorporated.

Scenario	Total Volume of Tidal Range	Locations	Speed of Deployment
Counterfactual	0 GW	N/A	N/A
Low Ambition	~1.5 GW	North West & South West	2037 – 2040
Medium Ambition	~5 GW	North West, South West & East	2035 – 2042
High Ambition	~8 GW	North West, South West & East	2032 – 2045

This project has assumed that the individual tidal range generation assets used in each scenario are of relatively consistent size and design. This standardisation allows a fair comparison of impacts on the grid arising from the different asset locations used in each scenario. The assets are assumed to be entirely offshore which has the potential to avoid higher sensitivity intertidal habitats and reduce consenting risk, although we have not aimed to assess these impacts as part of this study. **The study has not sought to replicate any specific proposed projects.**

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[1] *HM Treasury, Business case guidance for projects and programmes, 2024, Business case guidance for projects and programmes - GOV.UK*

[2] *NESO, Future Energy Scenario 2024 Hydrogen Evolution pathway, 2024, https://www.neso.energy/publications/future-energy-scenarios-fes*

[3] *NESO, Holistic Network Design, 2022, https://www.neso.energy/document/239466/download*

[4] *NESO, Beyond 2030, 2024, https://www.neso.energy/document/304756/download*

Five Case Summary

Strategic Case

The Strategic Case for a tidal range industry in Great Britain comes from the following context:

- NESO's 2024 Future Energy Scenarios (FES) predict that the Great Britain's (GB) electricity demand is to at least double by 2050 (compared to 2023). This projected increase is partly driven by the need to support continued economic growth, which includes rising modern consumer demands, and the expansion of high-energy-use sectors such as data centres and large scale electrified industrial users. In parallel, the UK Government has committed to reach net zero by 2050 and more recently, to delivering a fully clean power system by 2030[5], demonstrating the aspiration for low-carbon energy projects. Global events in recent years such as Russia's invasion of Ukraine and the knock-on increase in imported gas prices highlight the importance of domestic energy production to ensure energy security.
- The transition from centralised, dispatchable electricity generation to a renewables-led and therefore mainly decentralised and non-dispatchable supply will continue to lead to significant changes and challenges for the GB energy system in the coming decades.
- The introduction of strategic, centralised planning of energy generation in GB has the potential to offer an opportunity for tidal range generation assets to be considered alongside other emerging technologies in the future.
- Due to the high tidal ranges that occur around the UK's coastline, investigations into the potential for an active sector have been going on for more than 100 years. This culminated in 'The Role of Tidal Lagoons' report by Charles Hendry in 2016[6]. Commissioned by the government, the independent review found that 'the evidence is clear that tidal lagoons can play a cost-effective role in the UK's energy mix'.

Economic Case

Previously proposed tidal range energy schemes in the UK have been perceived as being high cost when compared with other forms of renewable energy generation because of their higher Levelised Cost of Energy (LCOE) compared to more mature technologies, such as wind and solar generation.

The scenarios modelled in this study aim to represent a range of possibilities from a focus on individually developed schemes (low ambition), through to a more centralised

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[5] *DESNZ, Clean Power 2030 Action Plan, 2024, https://www.gov.uk/government/publications/clean-power-2030-action-plan*

[6] *Charles Hendry, The Role of Tidal range generation assets, 2016*

approach to the roll-out of tidal range assets (high ambition) to give a broad picture of the potential scenarios for tidal range energy deployment. **It should be noted that the total installed capacity of the GB electricity system varies between the scenarios, and that in the counterfactual and low ambition scenarios, no additional capacity has been considered to replace the tidal range generation removed from the FES2024 HE pathway**.

The results show that when the total cost to the consumer is considered, including wholesale market costs, subsidy requirement and the impact on existing subsidies (Contracts for Difference (CfD)), and the cost of thermal constraint and energy balancing costs, the counterfactual scenario where no tidal range is included is the cheapest. However, when considering a Regulated Asset Base (RAB) financing mechanism, the total additional cost over the study period between the CF and low ambition (i.e. for an additional ~1.4GW of total capacity on the system, supplied by tidal range) comes to less than £0.5 billion (~0.1%). It should be noted that this would shift additional development and construction risk on to consumers.

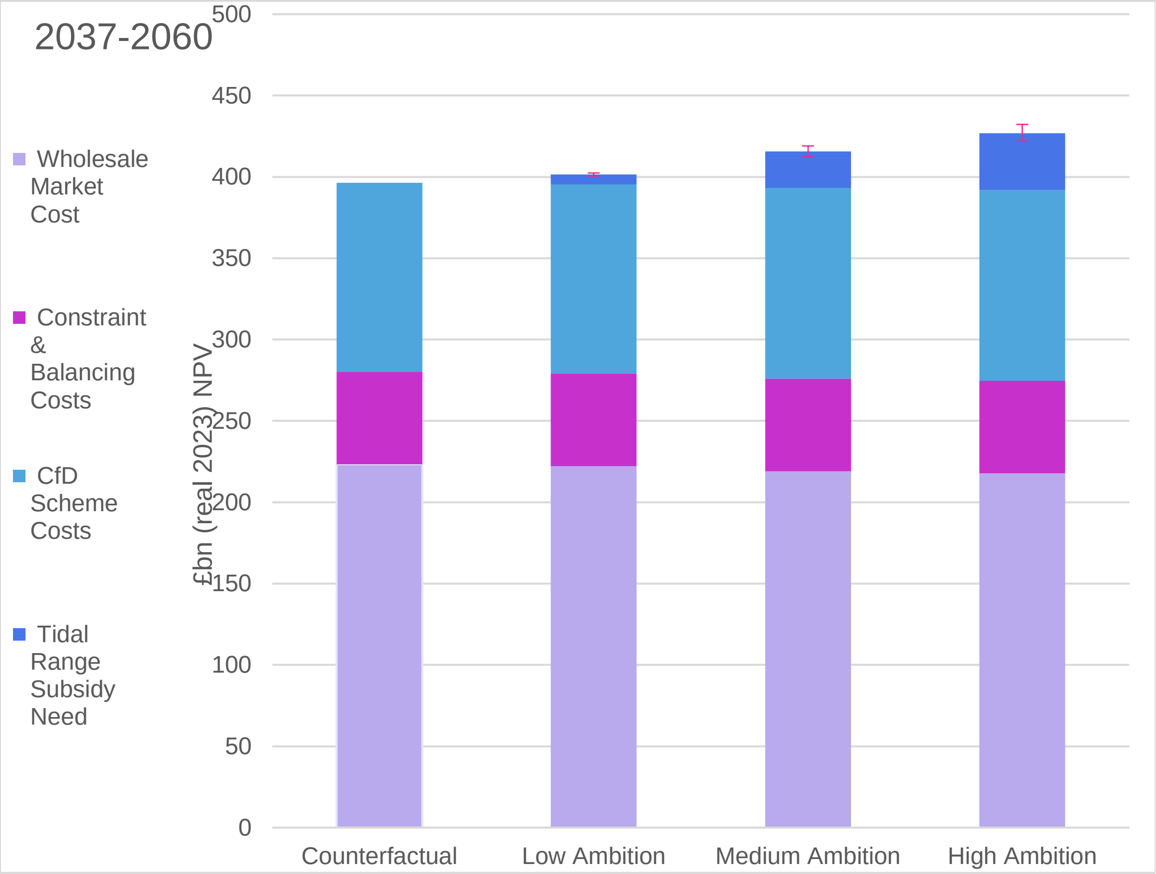
The study suggests that when tidal range generation assets are deployed in locations with high potential generation, there is minimal impact on the cost of energy balancing and thermal constraints, and the costs and benefits to the energy system could be reasonably balanced. Locations with high generation potential are those with large tidal ranges, such as the North-West of England and the Severn Estuary.

Under the RAB financing mechanism, the medium ambition scenario was approximately £2billion (0.6%) more expensive than the counterfactual over the study period, and the high ambition another £2billion (0.5%) more expensive than the medium.

Under the more traditional LCOE style financing mechanism. The medium ambition scenario was £19 billion (5%) more expensive than the counterfactual over the study period, and the high ambition another £12billion (3%) more expensive than the medium. These increases are due to the higher cost of financing increasing the subsidy cost.

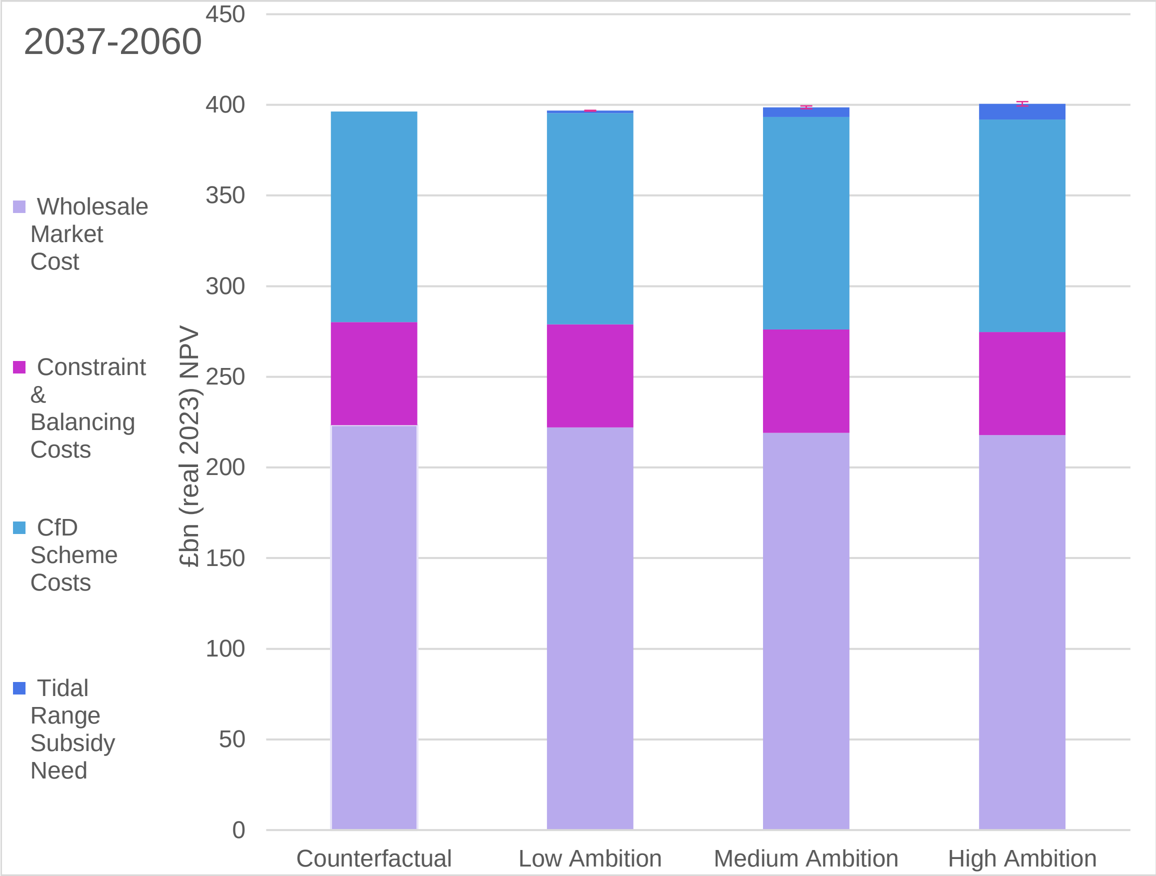
Under a RAB financing mechanism, the medium ambition scenario was approximately £2billion (0.6%) more expensive than the counterfactual over the study period, and the high ambition another £2billion (0.5%) more expensive than the medium.

Figure 0-1 shows the results when a Contract for Difference (CfD) type model is considered, and Figure 0-2 shows the results when a Regulatory Asset Based (RAB) based financing model is considered.



	Counterfactual		Low Ambition		**Medium Ambition**	High Ambition	
Wholesale Market Cost	223	(4)	222	(3)	**219**	218	1
Constraint & Balancing Costs	57	0	57	0	**57**	57	0
CfD Scheme Costs	116	1	116	1	**117**	117	0
Subsidy Need	-	22	6	16	**22**	35	(13)
Total	**396**	**19**	**401**	**14**	**416**	**427**	**(11)**
Number of Assets	0		2		7	11	
Tidal Range Capacity (GW)	0		1.4		5.1	7.8	
Total System Capacity change with respect to the Medium Ambition Scenario (GW)	-5.1		-3.7		0	2.7	

Figure 0-1: *Whole System Cost (£bn) comparison between scenarios (Non-regulated LCOE calculation). Note values in red show difference from medium ambition (medium ambition minus scenario). Note totals in the table may not sum due to compounded rounding.*



	Counterfactual		Low Ambition		**Medium Ambition**	High Ambition	
Wholesale Market Cost	223	(4)	222	(3)	**219**	218	1
Constraint & Balancing Costs	57	0	57	0	**57**	57	0
CfD Scheme Costs	116	1	116	1	**117**	117	0
Subsidy Need	-	5	1	4	**5**	9	(4)
Total	**396**	**2**	**397**	**2**	**399**	**401**	**(2)**
Number of Assets	0		2		7	11	
Tidal Range Capacity (GW)	0		1.4		5.1	7.8	
Total System Capacity change with respect to the Medium Ambition Scenario (GW)	-5.1		-3.7		0	2.7	

Figure 0-2: *Whole System Cost (£bn) comparison between scenarios (RAB subsidy mechanism) – Note values in red show difference from medium ambition (medium ambition minus scenario). Note totals in the table may not sum due to compounded rounding.*

The results show:

- Under the scenarios tested, when wholesale market costs, balancing costs and subsidy scheme costs are considered together, tidal range generation does not appear to deliver significant savings over the study period. However, under higher ambition scenarios, adding generation capacity to the system in the form of tidal range generation does not appear to in-crease costs significantly under the right conditions.
- Tidal range could have a role to play in the energy generation mix without causing excessive constraint and balancing costs to the energy network. All scenarios show similar levels of curtailment volume due to constraint and balancing and therefore cost, suggesting that up to 8GW of additional capacity on the system, delivered by tidal range could be achieved with minimal impact on constraint and balancing cost. This suggests tidal range assets could help to address some of the challenges associated with the resilience of the GB power network as traditional thermal generation retires and is replaced by intermittent renewable generation.
- There may be benefits to certain locations that offer better value to the consumer due to both favourable thermal constraints, as well as greater potential for higher generation and thus reduced LCOE due to high local tidal range. This highlights the need for a strategic approach to any future tidal range deployment.
- There would likely be a requirement for a subsidy, the cost of which is critical in determining the cost effectiveness of tidal range technology being deployed on the GB system.
- Additional tidal range generation, a zero short run marginal cost generator, drives down the wholesale market prices. This is countered by the cost to the consumer for a required tidal range subsidy, as well as a knock-on increase in the required spending for existing CfD contracts, designed to protect generators against wholesale price volatility and so subsidy payouts increase as the wholesale prices fall.
- There could be some additional benefits to the overall energy systems costs from co-located battery energy storage systems (BESS).
- Although not considered as part of the CBA analysis, tidal assets that can be synchronously connected to the GB grid have the potential to provide inertia, Short Circuit Level, and reactive power, and therefore reduce the need for NESO to procure services to address shortfalls. This in turn can help reduce system costs and ultimately costs to the consumer.

It is recommended that further studies could seek to develop a preferred option that optimises the constraint and balancing cost savings from the low ambition scenario with the wholesale market cost savings from a wider roll-out. This could be done by testing more combinations of location, scale and power modelling of assets which build on the results of this study.

It should be noted that the wholesale market price impacts are derived from only one potential 2024 future energy scenario, the Hydrogen Evolution pathway, and without comparing to other technology roll out to meet the same capacity requirements. These findings could therefore be further tested for the wholesale price impacts across a broader range of scenarios and sensitivities, as well as considering replacement background capacity to more closely match the FES scenarios.

Commercial Case

The modelling results suggest that tidal assets will be able to make revenues in the wholesale market by selling large volumes of power, however, their relatively high levelised costs indicate that a subsidy support mechanism would be required. In addition, as has been suggested by previous studies, it is expected that some form of government intervention would be beneficial in seeing the benefit of tidal range energy generation, for instance through a consistent approach to site selection, competition and regulations.

Furthermore, government support is likely to be required, at least initially, to de-risk the development and construction phase of the project because it would be the first tidal range generation asset deployed in UK waters. A Regulatory Asset Based (RAB) model has the potential to bring down the cost of capital, as compared to a CfD model, but would also place some of the development and construction risk with consumers or government.

The results also suggest that the high ambition scenario sees the least commercial affordability, due to the selection of generation assets in areas with smaller tidal range and less favourable bathymetry, leading to higher capital costs per MWh of generation – which can be seen in Table 0-1.

Financial Case

Results from this study show that introducing tidal range technology has the potential to be less expensive when a RAB financing mechanism is used rather than a traditional non-regulated LCOE (Levelised Cost of Energy) mechanism – such as CfD, as the cost of financing, and therefore the required subsidy assumed reduces. This is demonstrated in Table 0-1 which shows the variation in cost per MWh for the assets when varying the financing mechanism as well as the assumed hurdle rate or Weighted Average Cost of Capital (WACC) depending on the mechanism. However, it should be recognised that this would shift the construction risk to sit more with consumers.

Table 0-1: *Variation in average cost per MWh across generation assets depending on financial mechanism and cost of capital assumptions in brackets.*

Generation Asset Location	**LCOE (8.3%)**	**LCOE (9.3%)**	**LCOE (10.3%)**	**RAB (2.8%)**	**RAB (3.55%)**	**RAB (4.2%)**
North-West	£319	£367	£418	£105	£117	£129
Severn Estuary	£216	£249	£284	£68	£75	£83
North Wales & South Coast	£377	£434	£494	£121	£135	£149
East Coast	£658	£757	£863	£208	£232	£256

Management Case

In terms of delivery, the low ambition scenario demonstrates what is likely to be possible should the industry continue to be primarily developer led (and more recently, partnerships such as the Severn Estuary Commission have begun to develop more holistic knowledge bases at a regional level), and the associated legislative and planning obstacles limiting the speed of delivery remain. To enable a tidal range industry, speed up delivery, and encourage domestic supply chain scale-up, some government intervention to drive and lead development and delivery has been assumed. This is reflected in the assumptions made in the high ambition approach.

Recommendations

This study has shown that when considering the potential development of tidal range generation in the GB system, there are both potential benefits and risks to the consumer which need to be carefully balanced and considered.

The strategic recommendations include:

- Further explore the impact on consumer benefits of RAB, CfD and other financing models to ensure risks and costs to the consumer of different approaches are appropriately considered.
- Should tidal range generation be deployed in Great Britain, a strategic approach should be taken to ensure that asset location, capacity and deployment timings optimise the potential benefits for consumers (e.g. in wholesale price reductions) while maintaining low impact on the system (e.g. by delivering minimal impact on thermal constraint and energy balancing costs).

This study took a limited approach in terms of background scenario (FES24 Hydrogen Evolution) and the scenarios explored for tidal range deployment. Further future studies are therefore recommended to build on this work to build a more comprehensive assessment, with areas for further study including:

- Further refining of the scenarios to consider the best locations for tidal generation assets in order to try and maximise benefits to the GB consumer through:
    - Minimising wholesale markets costs and subsidies;
    - Impact of connection point location on system operation and local thermal constraint costs;
    - Size and timing of tidal range in different locations;
    - Socio-economic impact on local area including supply chain requirements;
    - Environmental impacts in different locations.

- Testing scenarios against a wider range of counterfactual scenarios and market conditions to improve the robustness of the study and confidence in the results, and to be able to compare to different alternative technology roll-out to meet capacity requirements.
- Further exploring potential supply chain locations for construction and assembly, and exploring the potential for centralised planning around this.
- Analysing different potential delivery models for taking forward development, construction and operations.

1. Strategic Case

Introduction and Project Scope

Project Context

Tidal Range Energy

1.1 Introduction and Project Scope

As the UK works toward achieving an energy transition from centralised fossil fuels to a system more dominated by zero carbon, renewable energy sources, the energy system faces multiple challenges. NESO's aim is to act as an independent, impartial voice to energy system planning and operations and to take a whole system view.

The tidal range industry promises predictable and reliable power, generating near population centres and providing semi dispatchable power and ancillary services to the GB electricity grid[7].

This aim of this project is to test the hypothesis that:

There is a strong case for the development of tidal range energy schemes in Great Britain, when considering how it is a predictable low-carbon energy source, its distance to population centres, and the potential speed of roll-out.

This has been explored through the development of this business case following the five-case model. The strategic case will be supplemented with PLEXOS modelling to assess the implications on the wider electricity system, including an analysis of future electricity demand and supply evolution, and estimated forecast wholesale electricity price with assumed tidal projects. This will:

- Allow NESO to assess the potential impact of assumed tidal projects on grid balancing and constraints.
- Allow NESO to establish the potential for future tidal range schemes, and understand their likely impacts, allowing more informed dialogue with potential developers or government-led proposals.
- Allow NESO to understand any potential role tidal range generation assets could play in the zero-carbon energy transition.

It should be noted that as the focus of this study is the GB energy system specifically, wider benefits that would typically be included in a business case such as job creation and potential flood protection are not being considered, as well as local environmental impacts. This study scope has been chosen to allow the specific energy system benefits at this stage to be calculated, bringing focus for NESO on their specific goals and objectives.

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[7] *Bringing forward tidal range potential in the UK, tidal range Alliance, February 2024, Library - British Hydropower Association*

1.2 Project Context

The following points offer context into why a study into the energy system impacts is timely:

- NESO's 2024 Future Energy Scenarios predict that the GB electricity demand is to at least double by 2050 (compared to 2023 demand). This projected increase is partly driven by the need to support continued economic growth, which includes rising modern consumer demands and the expansion of high-energy-use sectors such as data centres and large scaled electrified industrial users. In parallel, the UK Government has committed to reach net zero by 2050 and more recently, to delivering a clean power system by 2030, demonstrating the aspiration for low-carbon energy projects. Recent global events such as Russia's invasion of Ukraine and the knock-on increase in imported gas prices highlight the importance of domestic energy production to ensure energy security, which tidal range has the potential to offer as a sovereign, reliable, renewable source of generation.
- Another ongoing challenge facing the GB transmission network is thermal constraint management, and the associated costs being passed to consumers through curtailment and balancing costs. The transition from centralised, dispatchable electricity around which the GB grid was designed, to a renewable heavy and therefore mainly decentralised and non-dispatchable supply is causing challenges. Indeed, it has meant that the transmission of electricity from where it is generated to where it is consumed is not always possible, which is causing additional costs of curtailment and alternative generator ramp up. Therefore, the proximity of potential tidal range generation assets to areas of high demand could provide benefits to the market.
- The move to centralised, strategic spatial planning of energy generation in the UK has the potential to offer an opportunity to consider tidal range energy in the planning of the energy system in the future. Furthermore, the creation of Great British Energy offers a vehicle through which UK Government could seek to develop and invest in projects that offer clean, secure, home-grown energy.

1.3 Tidal Range Energy

1.3.1 Definition

Tidal range energy is a form of hydropower that converts the energy obtained from tides into electricity. Unlike weather-dependent generation, tidal energy is highly predictable, as tidal cycles follow regular and known patterns. This predictability makes tidal energy a reliable source of renewable energy.

1.3.2 Technological Overview

Tidal range energy generation relies on controlling the flow of water into and out of an impounded area of sea or estuary, creating a head difference across the structure which can then be used to generate electricity through turbines.

Tides are a consequence of the rotation of the earth and the interaction of the gravitational forces between the earth, the moon, and the sun. These forces cause the seas and oceans to move in and out relative to adjacent coastlines approximately twice a day. The tidal range at any given location is the difference between the highest and lowest water levels. Tidal ranges vary over time at any given location and generally vary between two extremes:

- Spring tides, which occur when the earth, the sun and the moon align on a common axis. In this scenario the gravitational forces exerted by the sun and the moon are complementary and result in more extreme high and low tides.
- Neap tides, which occur when the sun and the moon are perpendicular to each other with respect to the earth. In this scenario the moon's gravitational force counteracts a proportion of that of the sun, resulting in reduce high and low tides.

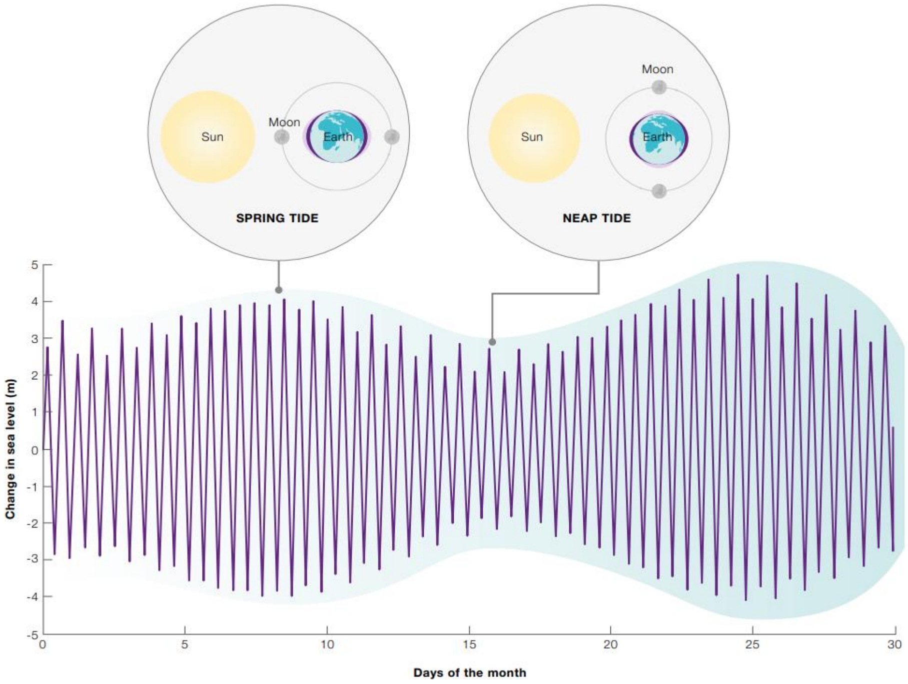

Figure 1-1: *Graph of tidal heights over time for 24 hours and 1 period for a non-specific site*

The variation over the two extremes occurs over the 28-day lunar cycle and the time of day that the high tide and low tide occur also varies between months. Over the course of the lunar monthly cycle the range of high tides will vary, resulting in a range of 'head' (the potential energy created by a difference in water heights) available for tidal power generation. This is evident in Figure 1-1, and effectively results in a cyclical variation in the available energy resource over the course of a lunar cycle. As a result, the load factor of a project will increase and decrease accordingly in the short term, above and below a long-term average. Local variations in tidal ranges depend on several factors including the topographic landscape and the volume of water able to enter the local area – typically a bay or estuary. This variation means that despite the UK being surrounded by water, not all locations around the country have a significant enough tidal range for it to be useful for electricity generation.

Several technologies have been developed to capture tidal range energy, including tidal lagoons and tidal barrages. The difference between these technologies is described below.

Barrages

A barrage is a dam-like structure built across a tidal basin or estuary, typically crossing from one bank to the other.

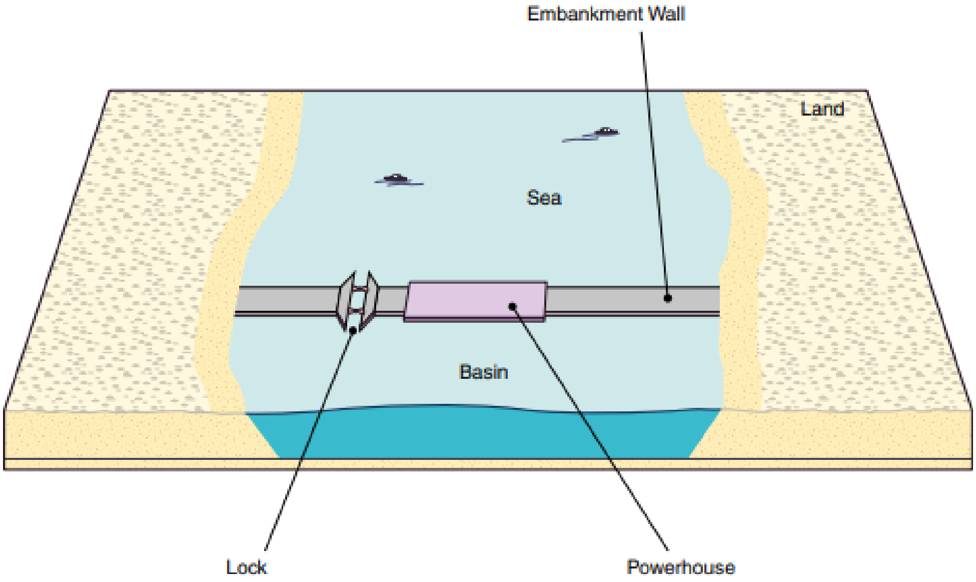

Figure 1-2: *Tidal barrage. Source: Arup*

Tidal lagoons

Tidal lagoons operate on the same principles as tidal barrages; however, they are self-contained structures which enclose a body of water but do not span full channels or estuaries. In doing so, they can reduce environmental and navigational impacts by allowing tide to flow uninterrupted in the remainder of the waterway**.**

Tidal lagoons can be either “onshore” (sometimes known as coastal lagoons) which are attached to the coastline, or “offshore” which are unattached, so the entire structure is constructed away from land.

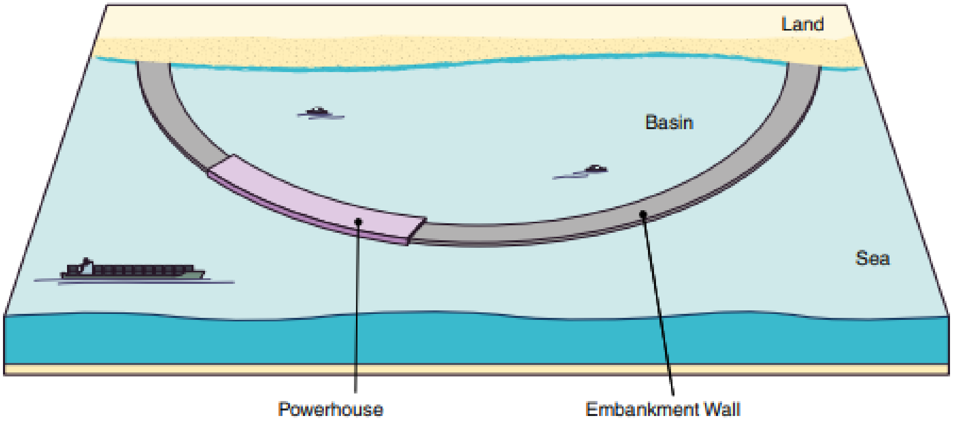

Figure 1-3: *Onshore lagoon (also known as coastal lagoon). Source: Arup*

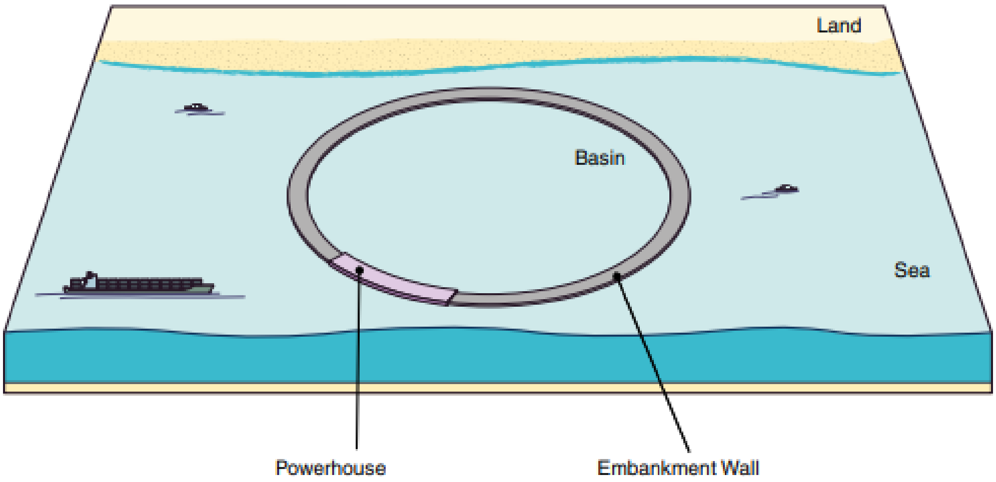

Figure 1-4: *Offshore lagoon. Source: Arup*

Modes of operation

Tidal range technology can generate energy in three operating modes: ebb generation, flood generation and two-way generation, as described below.

- **Ebb generation:** On a falling (ebb) tide, sluices in the barrage or lagoon are closed to retain water and are released under controlled conditions to allow water to flow through the turbine channel(s). On a rising tide, turbines are disabled and sluices are open, allowing water to freely enter the basin / impounded area.
- **Flood generation:** This mode operates in reverse to ebb generation and energy is captured using the rising, rather than the falling tide.
- **Two-way generation:** Two-way generation can be used to extend the generation window of tidal energy with a combination of ebb and flood generation, hence improving the load factor. Where ebb or flood generation would generate power twice in a 24-hour period, two-way generation could allow generation four times in the same period. The efficiency of generation for each tidal phase is slightly lower

for two-way generation, owing in part to the particular design of the turbines and the time required to maximise the head before the start of the next phase of generation. Overall, however, net production is typically increased with two-way operation and will improve the economic viability of a project.

Pumping

Pumping is used in tidal range energy schemes to run the turbines in reverse at times of low head differentials between the impounded area and the sea, in order to boost generating output. The low head differential means that a large amount of water can be transferred for a relatively small amount of energy, when compared to optimum generation. The additional water moved during the pumping time provides a greater overall head during the generation phase, meaning that more energy is obtained during that period than is expended during the pumping period. Figure 1-5 shows the energy generation cycle of a bi-directional tidal range scheme - the area in orange is relative to the energy generation. As can be seen on the right-hand side diagram, the energy expended within the green area results in a larger generation throughout the generation phase.

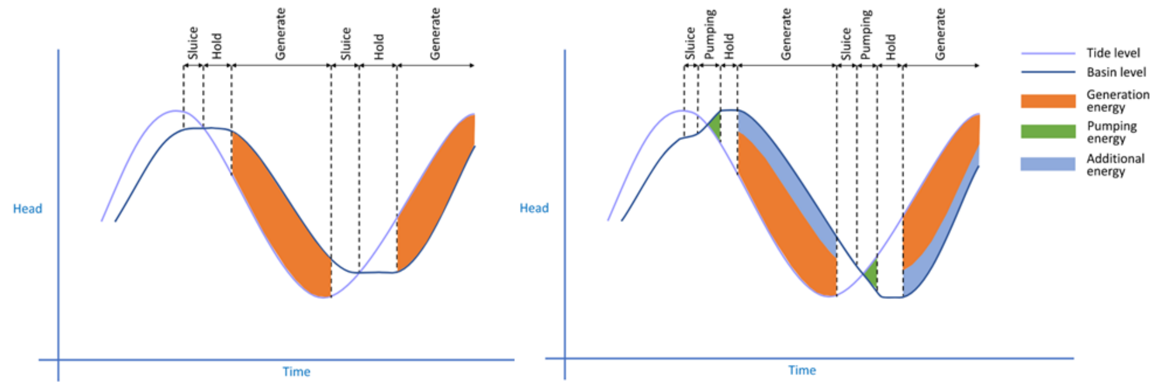

Figure 1-5: *Bi-directional generation (left) and bi-directional generation with pumping (right)*

There are two types of pumping which are generally applied to tidal range generation assets: mitigation pumping and performance pumping. Mitigation pumping aims to replicate the natural tidal cycle within the lagoon or upstream of the barrage, aiming to pump until the maximum or minimum tidal level of the previous cycle has been matched. Performance pumping aims to extract as much energy as possible, and pump to the point at which the energy balance between pumping and generation is optimised, resulting in pumping beyond the natural tidal cycle levels.

1.3.3 Tidal Range History

Despite the lack of deployed tidal range projects in the UK, investigations into the potential for an active sector have been going on for more than 100 years. Numerous studies and reports have been developed on the potential for tidal range projects across the UK, most of which have been specific to individual projects and have been undertaken by private developers with support from the public sector.

There are a number of operational tidal range schemes outside of the UK, including:

- La Rance Tidal Power Station in Brittany, France. Opened in 1966, this is a 750m-long tidal barrage across the Rance Estuary, with an installed capacity of 240MW.
- Sihwa Lake Tidal Power Station in South Korea. This barrage has an installed capacity of 254MW and was opened in 2011.
- Single-turbine barrage schemes in China and Russia.

Some wider-reaching studies have been developed by different UK Government agencies, both for tidal range technologies and specific sites or projects. This culminated in 'The Role of Tidal Lagoons' report by Charles Hendry in 2016[8]. Commissioned by the government, the independent review found that 'the evidence is clear that tidal lagoons can play a cost-effective role in the UK's energy mix'. Recommendations and conclusions from the report included:

- Power from tidal lagoons could make a strong contribution to UK energy security, as an indigenous and completely predictable form of supply.
- Moving ahead with a 'pathfinder' lagoon is a no-regrets policy.
- It is clear that tidal lagoons would contribute positively to progress towards the UK's decarbonisation goals.
- There is potential for large scale tidal lagoons to significantly decrease generation costs relative to a pathfinder project, due to site location and design.

More recently, the Severn Estuary Commission (established by the Western Gateway Partnership) assessed the feasibility of tidal range energy in the Severn Estuary[9]. The Commission's findings were supported by extensive stakeholder engagement and consultancy studies into the following aspects: environmental, socio-economic, funding and financing, grid connection, and engineering. Through this, the Commission concluded that the development of tidal range energy in the Severn Estuary is feasible, and projects would generate predictable low-carbon energy to help meet GB's growing electricity demand and contribute to grid stability. More specifically, the findings indicate that a tidal lagoon would be more optimal than a large barrage, due to negative environmental impacts, legislative barriers and impacts on ports and commercial activities.

According to the British Hydropower Association[10], there are eight projects currently being considered along the UK's west coast, from Cumbria to Somerset. With a total installed capacity of 20 GW, these projects have the potential to generate 30 TWh/year of electricity, accounting for 12% of the UK's energy demand. An example of one of these projects is Liverpool City Region's Mersey Tidal Power[11], which is currently in Phase 4 Concept Development.

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[8] *Charles Hendry, The Role of Tidal Lagoons, 2016*

[9] *Severn Estuary Commission, 2025, Final Recommendations - Severn Estuary Commission*

[10] *BHA, tidal range Key Statistics, tidal range - British Hydropower Association*

[11] *Mersey Tidal Power | Liverpool City Region Combined Authority*

2. Economic Case

Methodology

Assumptions and Caveats

Modelling Results

This section will outline the methodology and results that feed into the Cost Benefit Analysis that is the key aspect of the economic case. It should be noted that the primary focus of the study is the economic impact on the energy system rather than the potential economic impact overall. This analysis will take three scenarios with varying volumes and locations of tidal range energy assets included in the generation mix of the GB whole electricity system. This will be compared against a counterfactual scenario with no tidal range generation to explore the electricity system impacts.

2.1 Methodology

Figure 2-1 below offers a simplified workflow of how the Cost Benefit Analysis is assembled, from modelling of the tidal range assets, through a PLEXOS GB electricity system digital twin in order to understand impacts on thermal constraint and wholesale market price cost. These are then compiled for the different scenarios and can be compared to a counterfactual.

More detail into the specifics of this methodology is given below.

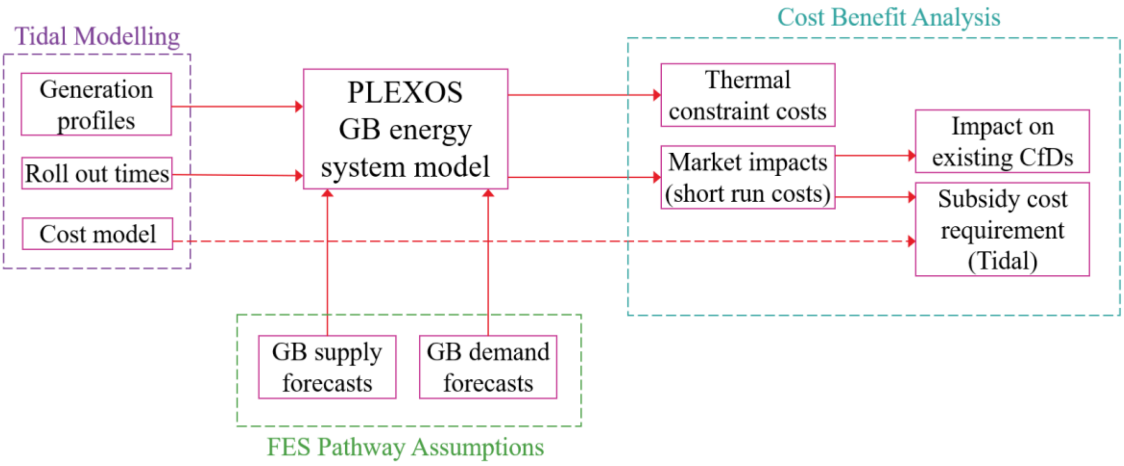

Figure 2-1: *Summary diagram of methodology*

2.1.1 Option Definition

The options considered as part of this study are scenarios comprising varying numbers of individual tidal range generation assets, which represent different pathways for the roll-out of assets across GB, and a counterfactual where there is no tidal range in the mix. **It should be noted that the individual assets used in this study do not represent any real-life proposed projects.**

2.1.2 Scenarios

To effectively model a range of potential impacts on grid connectivity and constraints, four scenarios have been developed: The counterfactual, low ambition, medium ambition and high ambition. Although they are options and assessed in their own right, they can also be used to define an 'envelope' as to the speed and degree of roll-out of tidal range assets. It is unlikely that one scenario would be developed exactly, however the range of scenarios considered has been chosen to give an overview of the possible impacts of different tidal range schemes.

In each scenario, different numbers of tidal range generation assets of similar capacity (~700MW) have been modelled in locations across GB (see Table 2-2) in areas with significant tidal ranges. Additional capacity has been added for the higher ambition scenarios by increasing the number of assets, rather than the capacity of an asset already modelled. This was decided to:

- Allow additional analysis of constraint and balancing by putting assets in areas around the country
- Maintain consistency of analysis to allow more nuanced conclusions to be drawn
- Allow more consistent designs should tidal range generation assets be rolled out, allowing for cost and programme savings

In general, the locations used in the low ambition scenario are those with the highest tidal range, with the higher ambition scenarios including areas that have a lower tidal range, though are still feasible.

For each of the scenarios the FES 2024 Hydrogen Evolution (HE) pathway has been used to model the remaining GB generation supply as well as predicted demand. It should be noted that in the FES 2024 HE Pathway, the total tidal capacity is for both tidal range and tidal stream projects – with most of the tidal capacity delivered by tidal range generation assets. However, this piece of work considers only tidal range generation, and for the purpose of simplicity assumes the entire tidal generation capacity is met by tidal range.

The decision to not include additional replacement capacity in the counterfactual or low ambition scenarios (thus comparing the whole market costs of systems with the same total generation capacity) was taken to prevent against the sensitivity of the wholesale market cost to the representation of this replacement capacity mix. This impact was identified through previous modelling runs undertaken as part of this project, and taking the approach to not include the replacement capacity means that it is possible to attribute any results solely to the addition or removal of tidal range assets. More information can be found on this in Section 2.3.6.

Table 2-1: *Scenario definitions (counterfactual, low, medium and high ambition)*

Scenario	Total Volume of tidal range	Boundaries	Speed of Deployment	Type of Technology	Strategic Reason
Counterfactual	0 GW Tidal generation capacity otherwise included in FES 2024 HE Pathway removed	N/A	N/A	N/A	Counterfactual required to model the alternative to the other scenarios. In the case of tidal range energy, this is the 'do nothing' option.
Low Ambition	~1.5 GW Additional tidal generation capacity otherwise included in FES 2024 HE Pathway removed	North West & South West	2037 - 2040	Traditional ebb & flood (with pumping)	Understanding system impacts of predictable generation, while considering high Capex etc. Low ambition represents publicly available information on schemes in development.
Medium Ambition	~5 GW Aligned with FES 2024 HE Pathway	South West, North West & East Coast	2035 - 2042	Traditional ebb & flood (with pumping)*	Range of schemes in areas of highest tidal range out to FES 2024 total. Wider range of tide times more akin to 'baseload'.
High Ambition	~8 GW tidal range	South West, North West & East Coast	2032 – 2045	Traditional ebb & flood (with pumping)	Maximum ambition to test lower cost of capital through maximising efficiencies. Using Clean Power 2030 assumptions to test earliest possible rollout.

*Includes a sensitivity with co-located battery storage

Battery sensitivity: A test was run with each asset co-located with a 4-hour duration battery of between 524 and 648MW peak capacity as a sensitivity to the medium ambition scenario. It is recognised that this is an unrealistic scenario but was run to illustrate the potential impact of adding battery capabilities, to understand whether additional flexibility improves the integration of tidal assets by reducing the constraint costs. Although tidal energy benefits from a high degree of predictability - since tidal patterns can be calculated far in advance - it is not dispatchable in the same way as flexible generation technologies. Power output is largely constrained by the timing and magnitude of the tides, limiting the ability to adjust generation outside these natural cycles to fit real-time grid needs. Adding a co-located battery to a tidal generator led to the creation of a hybrid generation asset which is better suited to cater for real-time grid needs due to higher degree of flexibility. The economic viability of these 4-hour co-located assets was not assessed. If they were unable to operate on a purely merchant basis, this would be reflected in a higher subsidy requirement for the hybrid asset.

2.1.3 Asset Rollout

The generation asset rollout order for each of the three scenarios is detailed in Table 2-2 below. It should be noted that these assets are theoretical, they do not relate to any real-world projects in development and do not preference any individual projects. The below table presents the rough location for the purpose of determining grid transmission boundaries and modelling alternative scenarios. See section 5 for more detail on the chosen programmes.

Table 2-2: *Asset rollout order.* ***Note: assets detailed here are theoretical, they do not relate to any real-world projects in development and do not preference any individual projects.***

Lagoon Phasing	Lagoon Location	Boundary ID (model)	High Ambition Year Online	Medium Ambition Year Online	Low Ambition Year Online
1	Liverpool Bay	B8	2032	2035	2037
2	Severn Estuary high	SW1	2033	2036	2040
3	Solway	B7	2034	2037	-
4	Humber Estuary	B8	2035	2038	-
5	North Wales	NW2	2036	2039	-
6	Severn Estuary low	RoGB	2037	2040	-
7	Morecambe Bay	B8	2038	2041	-
8	Thames	RoGB	2039	-	-
9	Ribble Estuary	B8	2040	-	-
10	Wash (outer)	RoGB	2041	-	-
11	Rye	SC1	2042	-	-

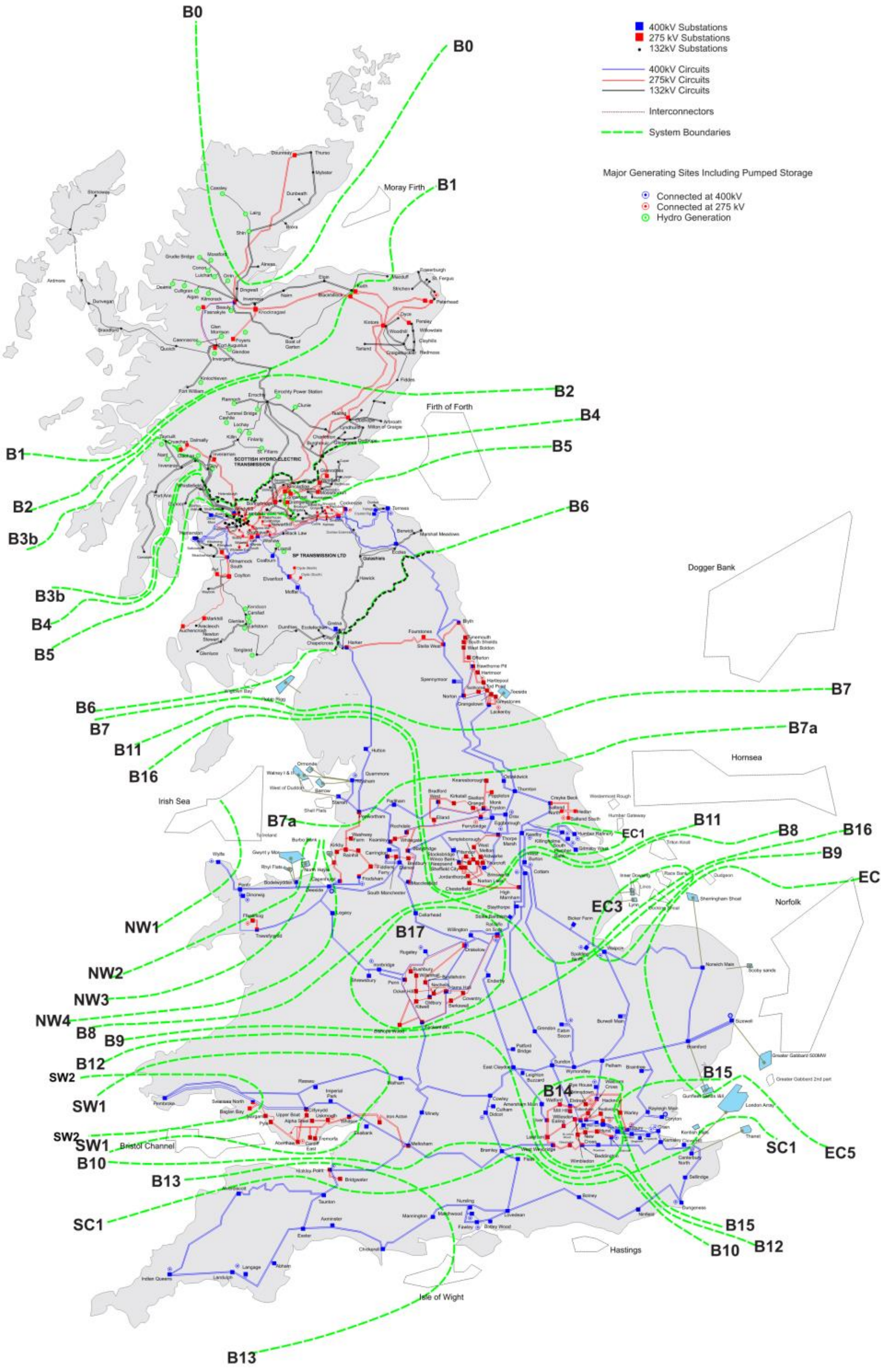

Figure 2-2: NESO map of GB System Boundaries

2.1.4 Asset Locations

Indicative locations of the tidal range generation assets for each scenario are shown in Figure 2-3, Figure 2-4 and Figure 2-5. These study locations do not relate to any projects in development and have been selected to allow for testing of transmission boundaries.

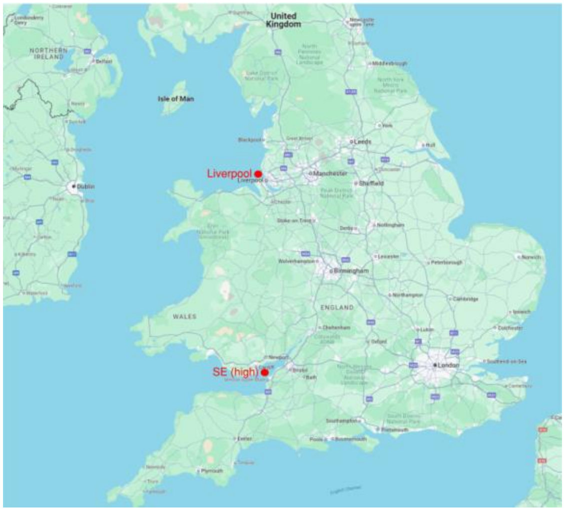

Figure 2-3: *Low ambition indicative locations*

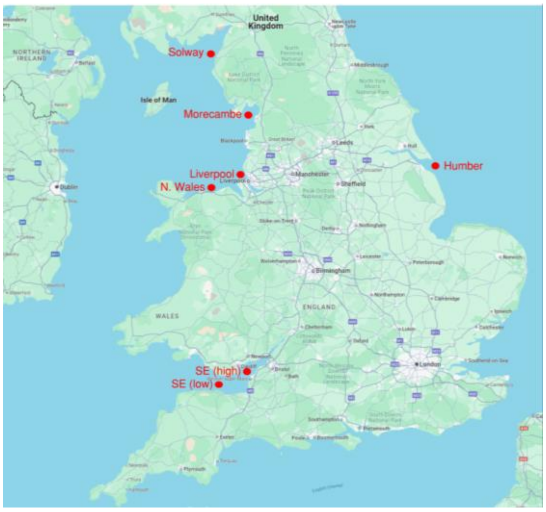

Figure 2-4: *Medium ambition indicative locations*

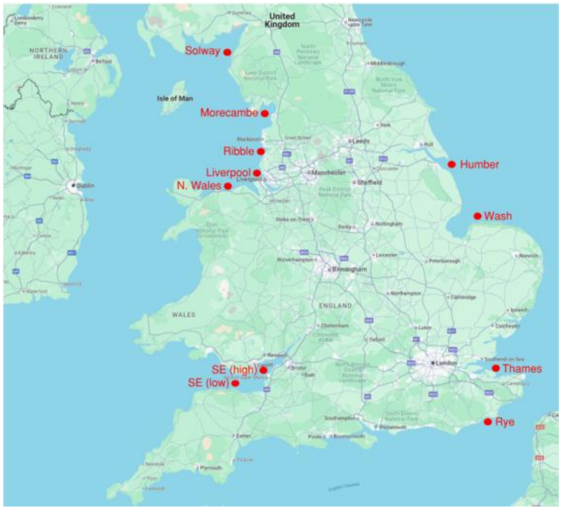

Figure 2-5: *High ambition indicative locations*

Note: assets detailed here are theoretical, they do not relate to any real-world projects in development and do not preference any individual projects

2.1.5 Tidal Modelling

Arup has previously developed a digital tool for modelling tidal range generation assets, the Arup Tidal Tool (ATT), to support early decision making on potential tidal range schemes. The ATT comprises a lagoon layout and bund volume model, and an energy generation model which provides an understanding of the geometry and energy generation capability for a tidal range project of a certain size and capacity. The energy model is a 0-D tidal power model which simulates energy outputs for the target cases outlined in section 2.1.2. The model simulates the flows through the turbines using a time step of one minute, and calculates the associated head, to estimate the power output over that time step.

To carry out the energy generation calculations, the tool utilises a number of parameters including:

- A defined lagoon outline
- A defined number of turbines and sluices in operation
- Location-specific tidal data
- Turbine operational data
- Pumping operational data

For the purposes of this study, the primary focus of modelling has been on the energy generation model to provide realistic energy generation profiles and pumping demand profiles to input into the PLEXOS energy system model. The tidal range projects have been set up to provide the agreed installed capacity for each scenario as outlined in Table 2-1.

The tides change over an 18-year lunar cycle. For this analysis, an “average” year of 2007 was adopted for modelling the tides. This average weather year was chosen to provide a mean annual renewable energy production (RES), and this weather pattern is assumed to repeat year-on-year for the duration of the power market modelling. It was agreed that for objectives of this study, modelling a minimum and maximum year would have limited benefit in the wider conclusions which could be drawn.

The operating method used in the ATT was bi-directional generation with performance pumping. There are control parameters within the pumping model that can be further refined on site specific conditions, such as the number of turbines running at a given tide size, or the dynamic start and stop heads. A general model was used for this study, but further optimisation is possible. The ATT takes into consideration the additional demand of the asset to power the pumps.

Additionally, the ATT carries out a bottom-up cost estimate for each of the tidal range generation assets, which is used as an input to the final Cost Benefit Analysis. More detail can be found on this in the Financial Case.

2.1.6 PLEXOS Modelling

NESO's Future Energy Scenarios 2024 (FES) provides different pathways for GB to meet its 2050 net zero obligations. The pathway selected for this analysis is the Hydrogen Evolution (HE) Pathway which sees the GB electricity demand increases from approximately 310TWh/yr today to 720TWh/yr in 2050. The HE Pathway was selected in agreement with NESO as it contains the highest amount of tidal capacity in its generation mix of the four pathways.

The modelling basis is to compare the energy system market response for the Hydrogen Evolution Pathway with the different tidal range power scenarios, set out in Table 1-1, against a counterfactual scenario in which the tidal range capacity is removed.

The Arup in-house Pan-European Power Market Model in PLEXOS was used to analyse the GB power system, assess constraint costs over the forecasting horizon, and evaluate their impact on the consumer. The GB system model captures the effects of changing boundary capabilities over time as reinforcements are deployed, influencing power flows and generator operations. However, the assumptions for grid development are restricted to the NESO Beyond 2030 assumptions[12]. Whilst this is the very latest set of assumptions, it is highly likely that there would be grid developments beyond 2035/6. These are not considered but would affect the cost of the tidal scenarios and the counterfactual scenario, particularly the constraint and balancing costs.

Two model runs are required for the counterfactual and each scenario: an unconstrained run, with no network limits, and a constrained 'redispatch' run with transmission constraints. This approach allows the network constraints to be analysed and costed based on assumptions on bids and offers. An average of the bid and offer prices over the last five years has been adopted. It uses the balancing market data from NETA reports[13] to calculate the average accepted bid and offer prices per technology within the GB boundary. These prices are then applied to the volume curtailed to arrive at a counterfactual cost estimate of constraints.

The modelling process is illustrated in Figure 2-6 and the grid topology used to represent the GB transmission grid in the constrained model is illustrated in Figure 2-7.

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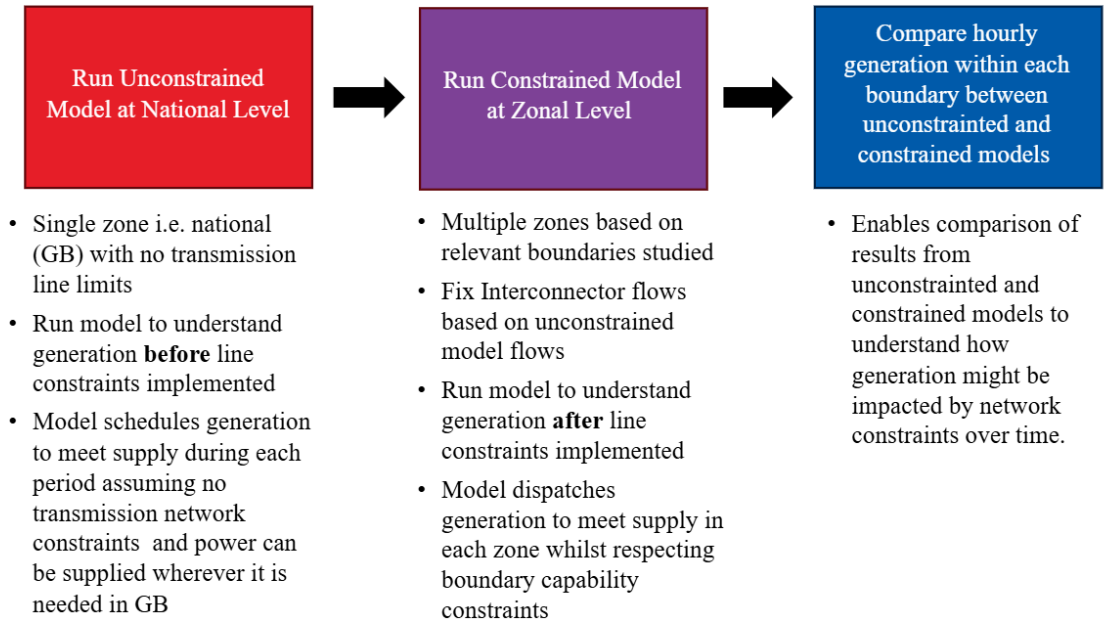
[12] NESO, Beyond 2030, 2024, https://www.neso.energy/document/304756/download

[13] *NETA Reports*



Run Unconstrained Model at National Level

- Single zone i.e. national (GB) with no transmission line limits
- Run model to understand generation **before** line constraints implemented
- Model schedules generation to meet supply during each period assuming no transmission network constraints and power can be supplied wherever it is needed in GB

Run Constrained Model at Zonal Level

- Multiple zones based on relevant boundaries studied
- Fix Interconnector flows based on unconstrained model flows
- Run model to understand generation **after** line constraints implemented
- Model dispatches generation to meet supply in each zone whilst respecting boundary capability constraints

Compare hourly generation within each boundary between unconstrainted and constrained models

- Enables comparison of results from unconstrainted and constrained models to understand how generation might be impacted by network constraints over time.

Figure 2-6: *Outline of PLEXOS modelling process to determine thermal constraints*

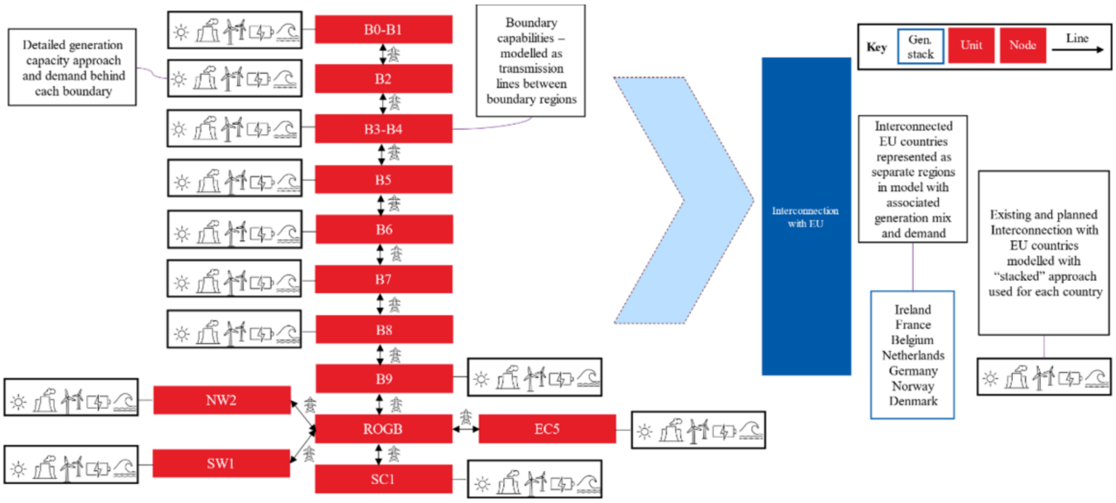


Figure 2-7: *PLEXOS modelling topology*

2.1.7 Cost Benefit Analysis

To compare the counterfactual with each of the three scenarios, the outputs from the modelling are compiled into a cost benefit analysis (CBA). The intention of this CBA is to reflect the overall cost to the GB consumer, comprising the wholesale market cost of electricity, the cost of constraint and balancing management as well as capturing the costs of delivering tidal range through the calculation of tidal range subsidy requirement, as well as the cost to honour CfD subsidy mechanisms as a knock-on impact of wholesale market cost changes.

Further detail into the methodology, as well as the results of the cost benefit analysis can be found in the Financial Case.

2.2 Assumptions and Caveats

FES 2024 Pathway – The market price impacts are modelled on one FES 2024 pathway, 'Hydrogen Evolution'. This is also adjusted to allow for assessment of tidal impacts. Therefore, the price impacts should be taken as indicative and only a sign of the potential price impacts.

Market design – This study assumes current market arrangements i.e. uniform pricing, CfD arrangements, capacity market arrangements, loss of load expectation.

Weather window – Only one weather year (2007) has been modelled. This year was chosen as it provides the most standard or average renewable energy generation, so as not to skew constraint management costs. As a result, extreme weather events have not been considered in this study.

Tidal asset performance – Optimising a tidal range asset's performance at a specific site has not been considered in this study.

Tidal asset type – Offshore tidal range generation assets have been modelled rather than considering barrages or coastal tidal range generation assets. The generation assets modelled were not intended to represent real world projects, but instead to be consistent where possible, to allow other nuances of the analysis to be considered. This project has assumed a series of tidal range generation assets of relatively consistent size and design, to allow potential for modularisation in engineering and construction and thus increased speed of deployment and reduction in cost as ambition increases. The assets are assumed to be entirely offshore which has the potential to avoid higher sensitivity inter-tidal habitats and reduce consenting risk.

Study period – The PLEXOS modelling has been run over the period from the generation asset being brought online up until 2050, when the FES modelling runs until. The economic modelling has then been extended out until 2060, assuming consistent PLEXOS outputs from 2050 to 2060.

Total GB capacity – There has been no modelled background capacity replacement for the Counterfactual or low ambition scenarios where the tidal range capacity has been removed from FES 2024 HE pathway. This was to allow the impacts recorded to be attributed conclusively to the addition or removal of tidal range generation only. Therefore, the different scenarios measure different total generation capacity for GB

2.3 Modelling Results

The following section details the output of the PLEXOS modelling, including the constraint and balancing impacts of the three tidal scenarios compared to the counterfactual; the impact on the whole-sale market price of electricity; and a discussion around the likely balancing services potential of tidal range.

2.3.1 Thermal Constraints and Energy Balancing- National Picture

To calculate the volume of curtailment due to constraint and balancing in each scenario, the PLEXOS model is run twice for each scenario – one unconstrained, i.e. with no network thermal constraints in the model – which represents the Day Ahead Market. Then the network thermal constraints and Energy Imbalance Actions are introduced and the PLEXOS model is run again – this represents the im-pacts of the Balancing Market. These volumes represent the volume of curtailed supply that according to the unconstrained day ahead market would have been favourable, but due to constraints both in network constraints but also in real time balancing supply and demand is no longer required.

In every scenario, as demonstrated by Figure 2-8, constraint and balancing costs rise over time because of the increasing share of renewable energy assumed in the FES 2024 Hydrogen Evolution (HE) pathway combined with the transmission grid assumptions of the Electricity Ten Year Statement (ETYS)[14] 2023 publication from NESO. It should be noted that the grid will continue to evolve past the assumptions made in this study, but for the purposes of comparison all scenarios have the same projected grid upgrades out until 2035 represented in the model.

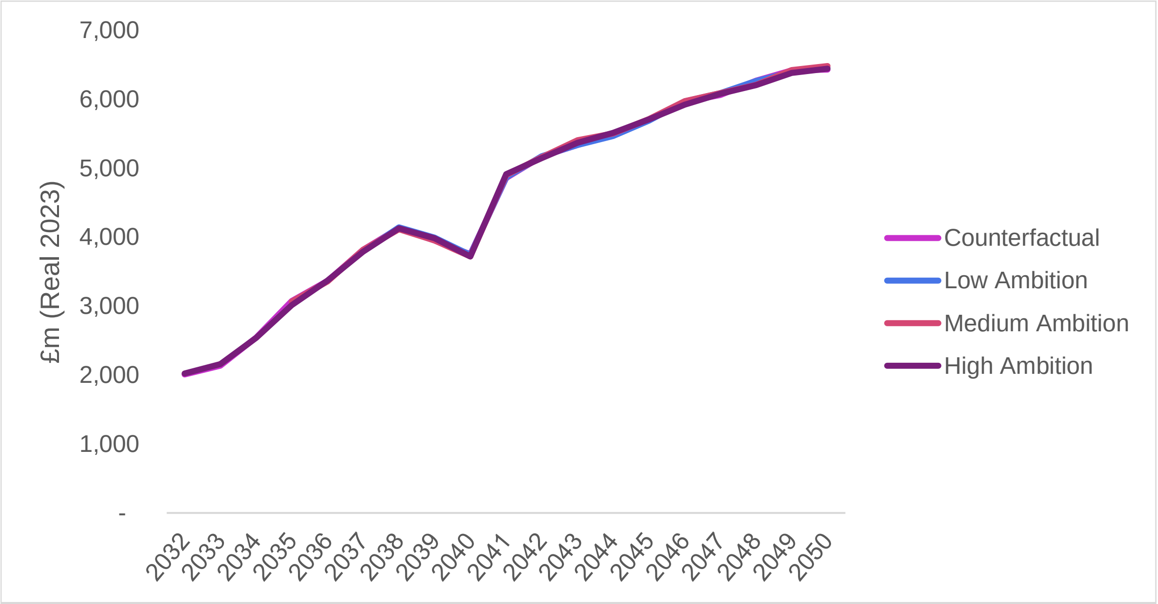


Figure 2-8: *Undiscounted Constraint and balancing cost curves by scenario across time*

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[14] https://www.neso.energy/publications/electricity-ten-year-statement-etys

Figure 1: Between 2037 and 2050 the four scenarios show very similar constraint and balancing costs.

Figure 2: A key finding from this study is that these costs are extremely similar between scenarios (within 0.2% over the study period, which may be attributed to inherent model variations), showing that the addition of tidal range energy assets to the system does not cause a significant overall increase in whole system constraint and balancing costs.

Table 2-3 below compares the total constraint and balancing cost for the four scenarios from 2037 to 2050 (common time range across the 4 scenarios):

Table 2-3: Undiscounted total constraint and balancing cost at the national level

Scenario	Constraint and Balancing Cost 2037-2050
Counterfactual	£73.3 billion
Low Ambition	£73.4 billion
Medium Ambition	£73.4 billion
High Ambition	£73.3 billion

These costs are driven primarily by two factors:

- the volume of tidal generation added, and the conventional generation it displaces, and
- the geographical location of the tidal projects.

Both factors differ across scenarios.

Figure 2-9, Figure 2-10 and Figure 2-11 show the change in constraint and balancing costs alongside the progression of generation capacity, show that the link between tidal capacity and constraint and balancing costs is not linear. This is logical as there will be other external factors that have a significant impact on constraint and balancing curtailment volumes and therefore cost, including upgrades to the transmission network, and other generation capacity being brought online in different locations.

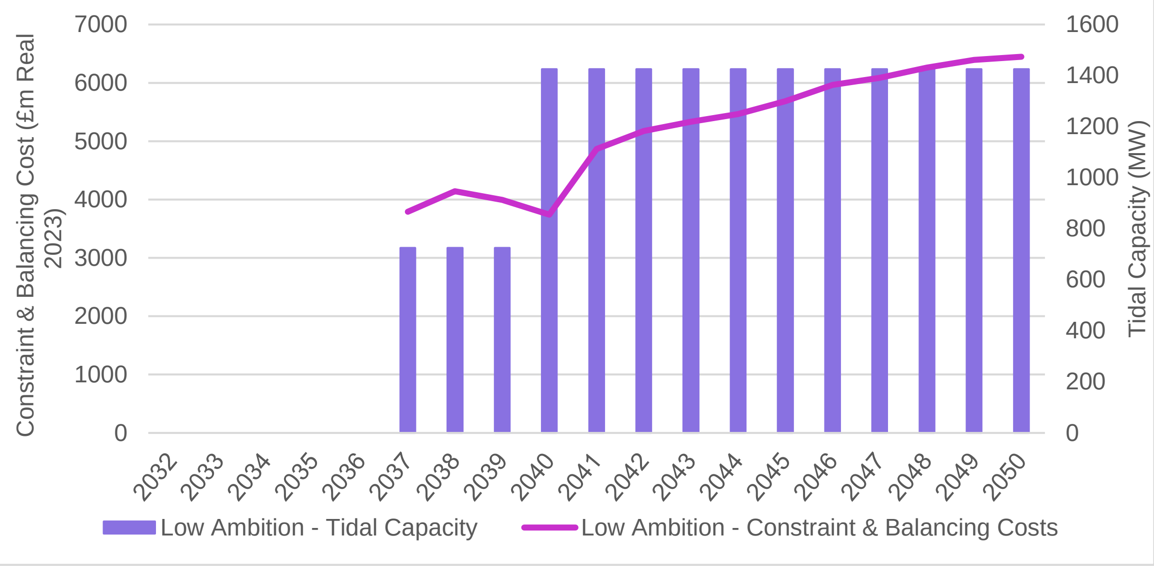


Figure 2-9: *Constraint and balancing cost per year shown against total tidal capacity (low ambition)*

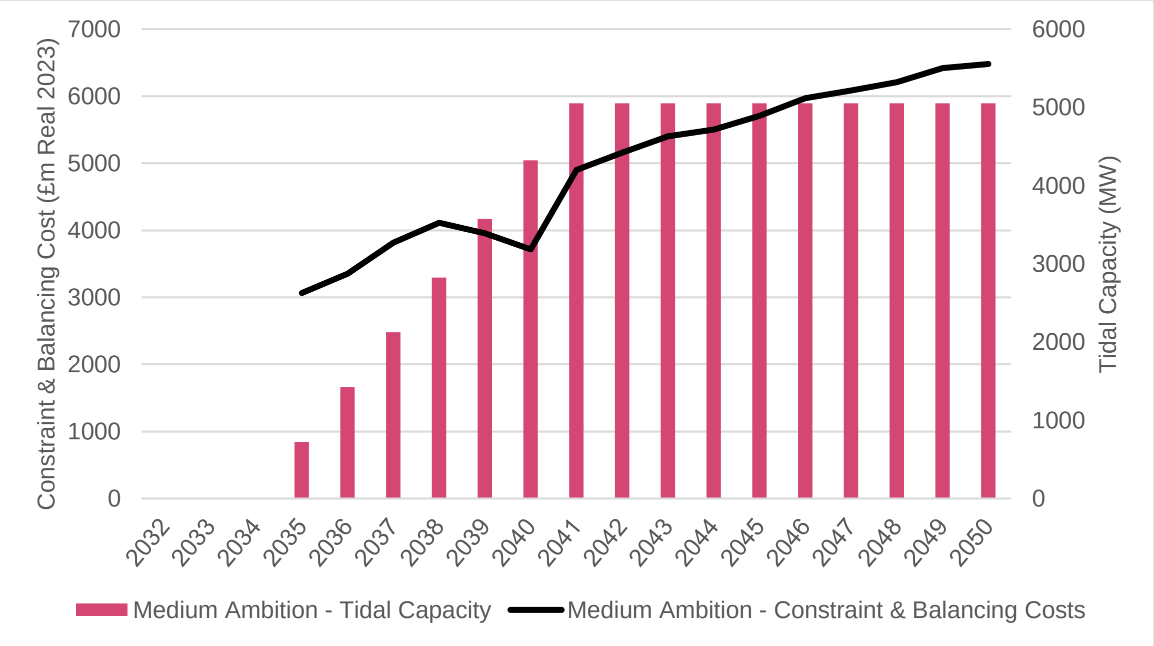


Figure 2-10: *Constraint and balancing cost per year shown against total tidal capacity (medium ambition)*

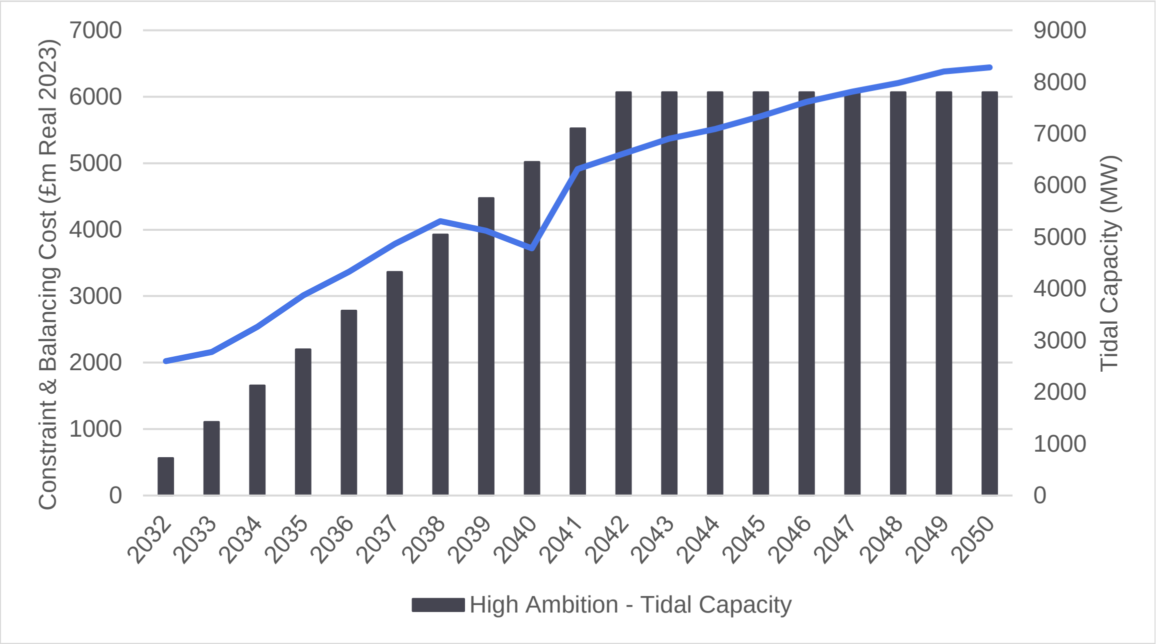


Figure 2-11: *Constraint and balancing cost per year shown against total tidal capacity (high ambition)*

2.3.2 Thermal Constraint and Energy Balancing – Transmission Boundary Level

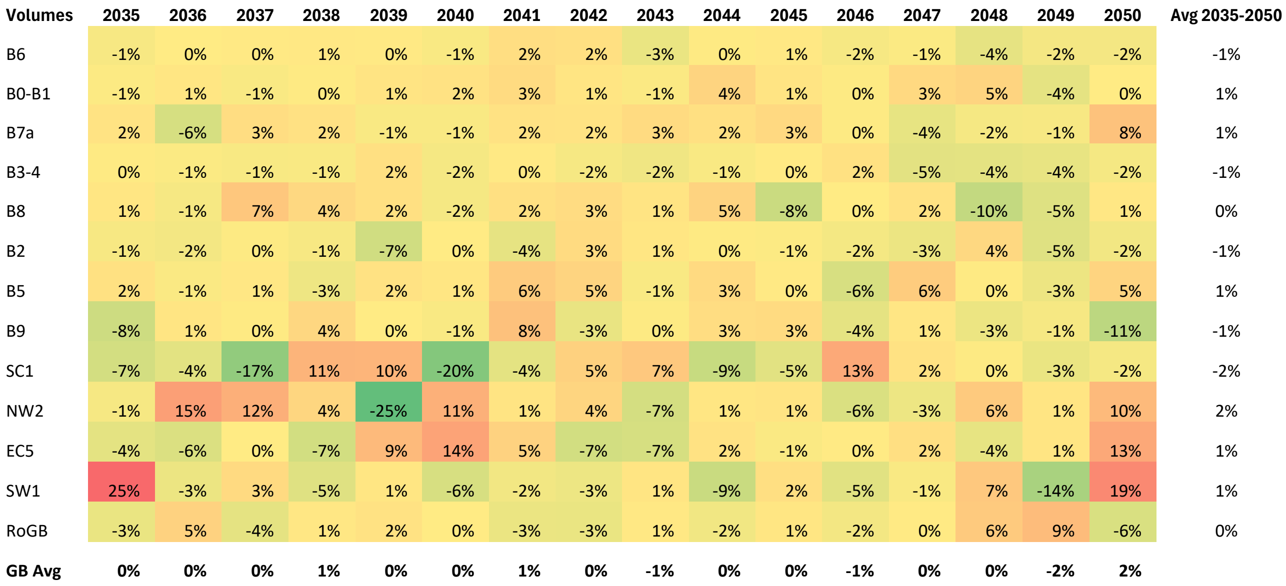
This section interprets the impact of each scenario when dividing constraint and balancing volume and cost between the modelled boundaries. Refer to Figure 2-2 for the location of the boundaries.

The following heatmap tables represent the change in constraint and balancing volume and cost be-tween the different scenarios, in each case comparing back to the medium ambition scenario, which is most closely aligned to the FES 2024 Hydrogen Evolution pathway.

High Ambition:

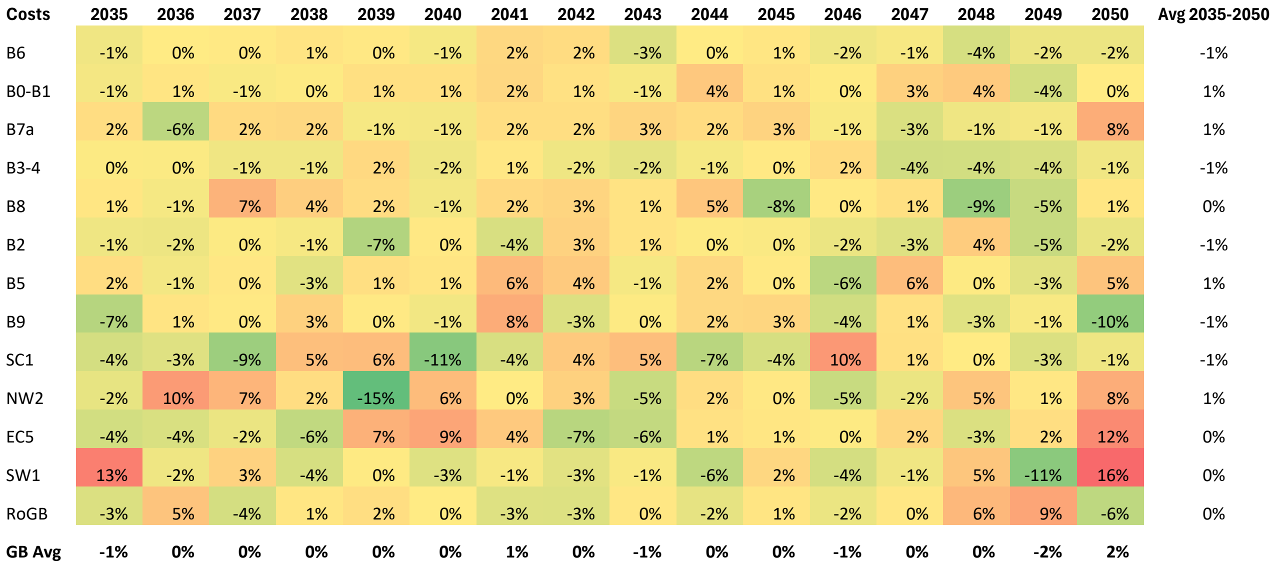
These heatmaps show the impact on the constraint and balancing volume and costs, when the high ambition scenario is compared to the medium ambition. Positive values show that when the additional generation capacity in the high ambition scenario is included in the supply, there is additional constraint and balancing volume in that boundary and therefore higher cost, and negative values represent less constraint and balancing volume, and respectively lower cost.

Table 2-4: *High Ambition – Constraint and balancing curtailment volume percentage change compared to the medium scenario*



Volumes	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	Avg 2035-2050
B6	-1%	0%	0%	1%	0%	-1%	2%	2%	-3%	0%	1%	-2%	-1%	-4%	-2%	-2%	-1%
B0-B1	-1%	1%	-1%	0%	1%	2%	3%	1%	-1%	4%	1%	0%	3%	5%	-4%	0%	1%
B7a	2%	-6%	3%	2%	-1%	-1%	2%	2%	3%	2%	3%	0%	-4%	-2%	-1%	8%	1%
B3-4	0%	-1%	-1%	-1%	2%	-2%	0%	-2%	-2%	-1%	0%	2%	-5%	-4%	-4%	-2%	-1%
B8	1%	-1%	7%	4%	2%	-2%	2%	3%	1%	5%	-8%	0%	2%	-10%	-5%	1%	0%
B2	-1%	-2%	0%	-1%	-7%	0%	-4%	3%	1%	0%	-1%	-2%	-3%	4%	-5%	-2%	-1%
B5	2%	-1%	1%	-3%	2%	1%	6%	5%	-1%	3%	0%	-6%	6%	0%	-3%	5%	1%
B9	-8%	1%	0%	4%	0%	-1%	8%	-3%	0%	3%	3%	-4%	1%	-3%	-1%	-11%	-1%
SC1	-7%	-4%	-17%	11%	10%	-20%	-4%	5%	7%	-9%	-5%	13%	2%	0%	-3%	-2%	-2%
NW2	-1%	15%	12%	4%	-25%	11%	1%	4%	-7%	1%	1%	-6%	-3%	6%	1%	10%	2%
EC5	-4%	-6%	0%	-7%	9%	14%	5%	-7%	-7%	2%	-1%	0%	2%	-4%	1%	13%	1%
SW1	25%	-3%	3%	-5%	1%	-6%	-2%	-3%	1%	-9%	2%	-5%	-1%	7%	-14%	19%	1%
RoGB	-3%	5%	-4%	1%	2%	0%	-3%	-3%	1%	-2%	1%	-2%	0%	6%	9%	-6%	0%
GB Avg	**0%**	**0%**	**0%**	**1%**	**0%**	**0%**	**1%**	**0%**	**-1%**	**0%**	**0%**	**-1%**	**0%**	**0%**	**-2%**	**2%**	

Table 2-5: *High Ambition – Constraint and balancing cost percentage change compared to the medium scenario*



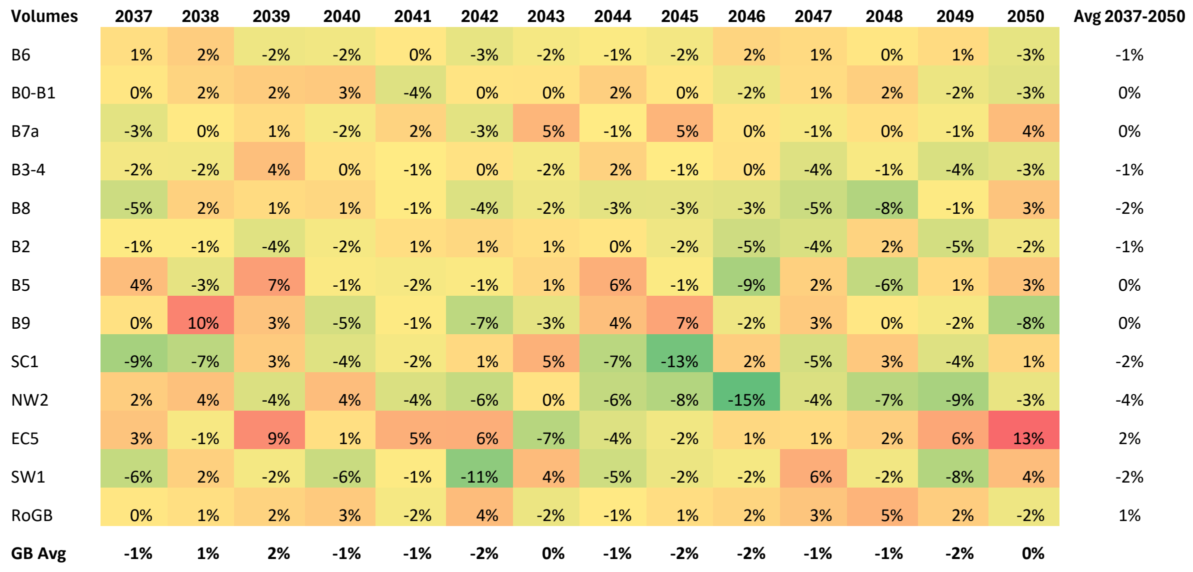
Costs	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	Avg 2035-2050
B6	-1%	0%	0%	1%	0%	-1%	2%	2%	-3%	0%	1%	-2%	-1%	-4%	-2%	-2%	-1%
B0-B1	-1%	1%	-1%	0%	1%	1%	2%	1%	-1%	4%	1%	0%	3%	4%	-4%	0%	1%
B7a	2%	-6%	2%	2%	-1%	-1%	2%	2%	3%	2%	3%	-1%	-3%	-1%	-1%	8%	1%
B3-4	0%	0%	-1%	-1%	2%	-2%	1%	-2%	-2%	-1%	0%	2%	-4%	-4%	-4%	-1%	-1%
B8	1%	-1%	7%	4%	2%	-1%	2%	3%	1%	5%	-8%	0%	1%	-9%	-5%	1%	0%
B2	-1%	-2%	0%	-1%	-7%	0%	-4%	3%	1%	0%	0%	-2%	-3%	4%	-5%	-2%	-1%
B5	2%	-1%	0%	-3%	1%	1%	6%	4%	-1%	2%	0%	-6%	6%	0%	-3%	5%	1%
B9	-7%	1%	0%	3%	0%	-1%	8%	-3%	0%	2%	3%	-4%	1%	-3%	-1%	-10%	-1%
SC1	-4%	-3%	-9%	5%	6%	-11%	-4%	4%	5%	-7%	-4%	10%	1%	0%	-3%	-1%	-1%
NW2	-2%	10%	7%	2%	-15%	6%	0%	3%	-5%	2%	0%	-5%	-2%	5%	1%	8%	1%
EC5	-4%	-4%	-2%	-6%	7%	9%	4%	-7%	-6%	1%	1%	0%	2%	-3%	2%	12%	0%
SW1	13%	-2%	3%	-4%	0%	-3%	-1%	-3%	-1%	-6%	2%	-4%	-1%	5%	-11%	16%	0%
RoGB	-3%	5%	-4%	1%	2%	0%	-3%	-3%	0%	-2%	1%	-2%	0%	6%	9%	-6%	0%
GB Avg	**-1%**	**0%**	**0%**	**0%**	**0%**	**0%**	**1%**	**0%**	**-1%**	**0%**	**0%**	**-1%**	**0%**	**0%**	**-2%**	**2%**	

Table 2-4 and Table 2-5 also show that there is no simplistic linear relationship between the introduction of tidal generators in a boundary and the direct impact on the constraint and balancing volume at the boundary level. B8 is the boundary which receives the greatest number of tidal generators and yet, the overall impact relative the counterfactual scenario is negligible over the period 2035-2050. The reason why there is no simple linear relationship between the introduction of tidal energy generators and the impact on the volume of constraint and balancing is because the overall impact is a function of the evolution of the transmission capacity of a given boundary with the rest of the network and the market dynamics across the rest of the GB transmission network.

Low Ambition:

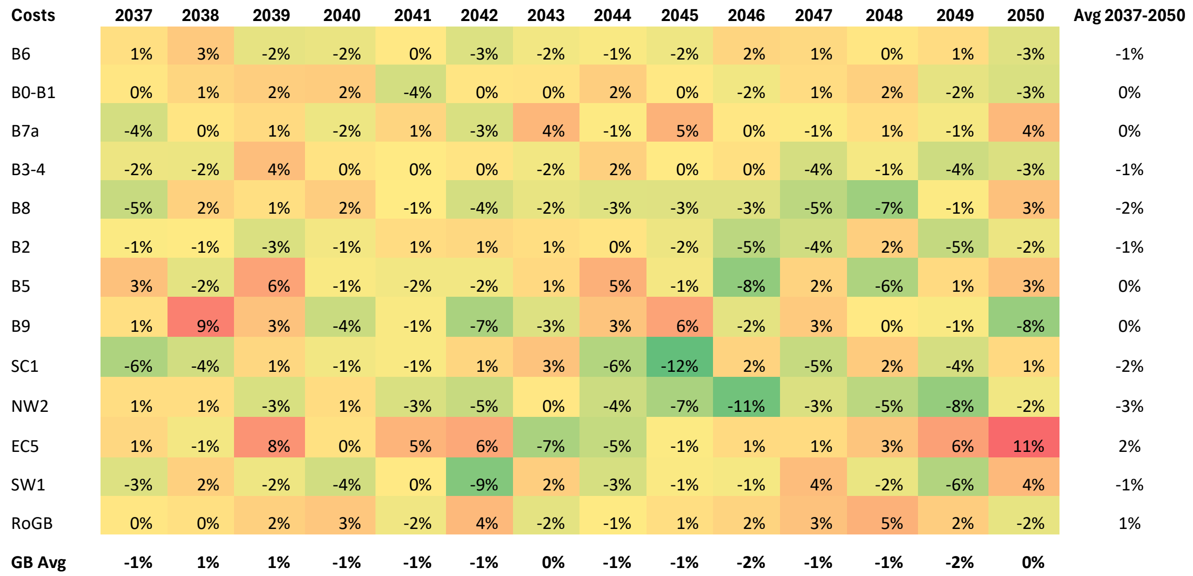
These heatmaps show the impact on the constraint and balancing volume and costs, when the low ambition scenario is compared to the medium ambition.

Table 2-6: *Low ambition – Constraint and balancing curtailment volume percentage change compared to the medium scenario*



Volumes	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	Avg 2037-2050
B6	1%	2%	-2%	-2%	0%	-3%	-2%	-1%	-2%	2%	1%	0%	1%	-3%	-1%
B0-B1	0%	2%	2%	3%	-4%	0%	0%	2%	0%	-2%	1%	2%	-2%	-3%	0%
B7a	-3%	0%	1%	-2%	2%	-3%	5%	-1%	5%	0%	-1%	0%	-1%	4%	0%
B3-4	-2%	-2%	4%	0%	-1%	0%	-2%	2%	-1%	0%	-4%	-1%	-4%	-3%	-1%
B8	-5%	2%	1%	1%	-1%	-4%	-2%	-3%	-3%	-3%	-5%	-8%	-1%	3%	-2%
B2	-1%	-1%	-4%	-2%	1%	1%	1%	0%	-2%	-5%	-4%	2%	-5%	-2%	-1%
B5	4%	-3%	7%	-1%	-2%	-1%	1%	6%	-1%	-9%	2%	-6%	1%	3%	0%
B9	0%	10%	3%	-5%	-1%	-7%	-3%	4%	7%	-2%	3%	0%	-2%	-8%	0%
SC1	-9%	-7%	3%	-4%	-2%	1%	5%	-7%	-13%	2%	-5%	3%	-4%	1%	-2%
NW2	2%	4%	-4%	4%	-4%	-6%	0%	-6%	-8%	-15%	-4%	-7%	-9%	-3%	-4%
EC5	3%	-1%	9%	1%	5%	6%	-7%	-4%	-2%	1%	1%	2%	6%	13%	2%
SW1	-6%	2%	-2%	-6%	-1%	-11%	4%	-5%	-2%	-2%	6%	-2%	-8%	4%	-2%
RoGB	0%	1%	2%	3%	-2%	4%	-2%	-1%	1%	2%	3%	5%	2%	-2%	1%
GB Avg	**-1%**	**1%**	**2%**	**-1%**	**-1%**	**-2%**	**0%**	**-1%**	**-2%**	**-2%**	**-1%**	**-1%**	**-2%**	**0%**	

Table 2-7: *Low ambition - Constraint and balancing cost percentage change compared to the medium scenario*



Costs	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	Avg 2037-2050
B6	1%	3%	-2%	-2%	0%	-3%	-2%	-1%	-2%	2%	1%	0%	1%	-3%	-1%
B0-B1	0%	1%	2%	2%	-4%	0%	0%	2%	0%	-2%	1%	2%	-2%	-3%	0%
B7a	-4%	0%	1%	-2%	1%	-3%	4%	-1%	5%	0%	-1%	1%	-1%	4%	0%
B3-4	-2%	-2%	4%	0%	0%	0%	-2%	2%	0%	0%	-4%	-1%	-4%	-3%	-1%
B8	-5%	2%	1%	2%	-1%	-4%	-2%	-3%	-3%	-3%	-5%	-7%	-1%	3%	-2%
B2	-1%	-1%	-3%	-1%	1%	1%	1%	0%	-2%	-5%	-4%	2%	-5%	-2%	-1%
B5	3%	-2%	6%	-1%	-2%	-2%	1%	5%	-1%	-8%	2%	-6%	1%	3%	0%
B9	1%	9%	3%	-4%	-1%	-7%	-3%	3%	6%	-2%	3%	0%	-1%	-8%	0%
SC1	-6%	-4%	1%	-1%	-1%	1%	3%	-6%	-12%	2%	-5%	2%	-4%	1%	-2%
NW2	1%	1%	-3%	1%	-3%	-5%	0%	-4%	-7%	-11%	-3%	-5%	-8%	-2%	-3%
EC5	1%	-1%	8%	0%	5%	6%	-7%	-5%	-1%	1%	1%	3%	6%	11%	2%
SW1	-3%	2%	-2%	-4%	0%	-9%	2%	-3%	-1%	-1%	4%	-2%	-6%	4%	-1%
RoGB	0%	0%	2%	3%	-2%	4%	-2%	-1%	1%	2%	3%	5%	2%	-2%	1%
GB Avg	**-1%**	**1%**	**1%**	**-1%**	**-1%**	**-1%**	**0%**	**-1%**	**-1%**	**-2%**	**-1%**	**-1%**	**-2%**	**0%**	

These tables show a mixed picture across both the different boundaries and the different years. Across different boundaries and years there are times and places where the reduction in tidal range generation is making curtailment worse, whereas in others the impact is the opposite and there is a reduction in the volumes and thus cost. This suggests that the impact depends on local fluctuations in supply and demand across both regions and time, reflecting that in some instances, when there is high demand, additional supply of tidal range will be beneficial, but that in some cases the generation occurs at times and in locations where demand is low (e.g. in the middle of the night) and this increases the volume of curtailment required.

The greatest savings are between 2 and 4%, in B8, SC1, NW2 and SW1, and the greatest increase is 2% in EC5. However, all of these boundaries show variance from these trends across different years.

Counterfactual:

These heatmaps show the impact on the constraint and balancing volume and costs, when the counterfactual is compared to the medium ambition.

Table 2-8: *Counterfactual – Constraint and balancing curtailment volume percentage change compared to the medium ambition*

Volumes	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	Avg 2035-2050
B6	1%	1%	2%	3%	-1%	0%	0%	0%	-2%	1%	-1%	-2%	-1%	-1%	2%	-3%	0%
B0-B1	2%	2%	0%	-1%	2%	4%	-5%	1%	2%	-2%	1%	0%	1%	1%	-1%	-3%	0%
B7a	2%	-6%	-2%	0%	0%	0%	3%	-2%	-3%	-2%	1%	0%	1%	0%	-3%	6%	0%
B3-4	-2%	1%	1%	0%	4%	3%	-1%	-3%	1%	0%	-1%	4%	-4%	-1%	-3%	0%	0%
B8	1%	-3%	-3%	-1%	3%	5%	3%	4%	-5%	1%	-6%	2%	1%	1%	-1%	-1%	0%
B2	2%	-2%	-3%	-4%	-1%	-3%	-2%	3%	1%	1%	1%	-3%	-1%	0%	-5%	-3%	-1%
B5	2%	1%	2%	0%	5%	-3%	-6%	2%	1%	3%	-3%	-5%	3%	-5%	0%	-6%	-1%
B9	-2%	-1%	1%	6%	-9%	2%	-4%	-9%	-3%	3%	2%	-4%	2%	-7%	-2%	-12%	-2%
SC1	0%	8%	-14%	-6%	7%	-6%	-6%	-2%	8%	-10%	-3%	-5%	-3%	11%	-6%	1%	-2%
NW2	4%	9%	-17%	-5%	-12%	12%	-4%	-11%	-1%	-4%	-3%	-4%	1%	-8%	-2%	11%	-2%
EC5	-1%	-1%	2%	-8%	-2%	-1%	7%	-1%	-9%	0%	-1%	0%	6%	-1%	5%	10%	0%
SW1	-9%	-20%	-5%	2%	6%	0%	-10%	-1%	1%	-14%	1%	-1%	8%	-7%	-11%	9%	-3%
RoGB	-2%	2%	0%	2%	-1%	0%	-2%	1%	-1%	1%	1%	0%	-2%	4%	4%	-3%	0%
GB Avg	**0%**	**-1%**	**-3%**	**-1%**	**0%**	**1%**	**-2%**	**-1%**	**-1%**	**-2%**	**-1%**	**-1%**	**1%**	**-1%**	**-2%**	**1%**	

Table 2-9: *Counterfactual – Constraint and balancing cost percentage change compared to the medium ambition*

Costs	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	Avg 2035-2050
B6	1%	1%	2%	3%	-1%	0%	0%	0%	-2%	1%	-1%	-2%	-1%	-1%	2%	-3%	0%
B0-B1	2%	2%	1%	-1%	1%	3%	-5%	1%	1%	-1%	1%	0%	1%	1%	-1%	-2%	0%
B7a	2%	-6%	-2%	0%	0%	0%	2%	-2%	-3%	-2%	1%	-1%	2%	1%	-3%	6%	0%
B3-4	-2%	1%	1%	0%	4%	3%	-1%	-3%	1%	0%	-1%	4%	-4%	-1%	-3%	0%	0%
B8	2%	-2%	-3%	-1%	2%	5%	2%	4%	-4%	1%	-5%	3%	1%	1%	-1%	-1%	0%
B2	1%	-2%	-3%	-4%	-1%	-2%	-2%	3%	1%	2%	1%	-3%	-1%	0%	-5%	-3%	-1%
B5	2%	0%	1%	0%	4%	-2%	-6%	1%	0%	3%	-3%	-6%	3%	-4%	0%	-5%	-1%
B9	-1%	-1%	1%	6%	-8%	1%	-4%	-9%	-2%	2%	1%	-4%	2%	-7%	-1%	-11%	-2%
SC1	0%	5%	-9%	-3%	3%	-3%	-5%	-2%	5%	-8%	-3%	-5%	-3%	9%	-6%	1%	-1%
NW2	2%	5%	-8%	-3%	-8%	6%	-3%	-8%	-1%	-3%	-2%	-3%	1%	-6%	-2%	9%	-1%
EC5	-1%	-1%	2%	-6%	-2%	-1%	5%	0%	-8%	0%	0%	0%	6%	0%	5%	10%	1%
SW1	-5%	-9%	-2%	1%	2%	0%	-7%	-1%	-1%	-11%	1%	-1%	5%	-6%	-9%	8%	-2%
RoGB	-2%	2%	0%	2%	-1%	1%	-2%	1%	-1%	1%	1%	0%	-2%	4%	4%	-3%	0%

GB Avg	**0%**	**0%**	**-2%**	**0%**	**0%**	**1%**	**-2%**	**-1%**	**-1%**	**-1%**	**-1%**	**-1%**	**1%**	**-1%**	**-2%**	**0%**

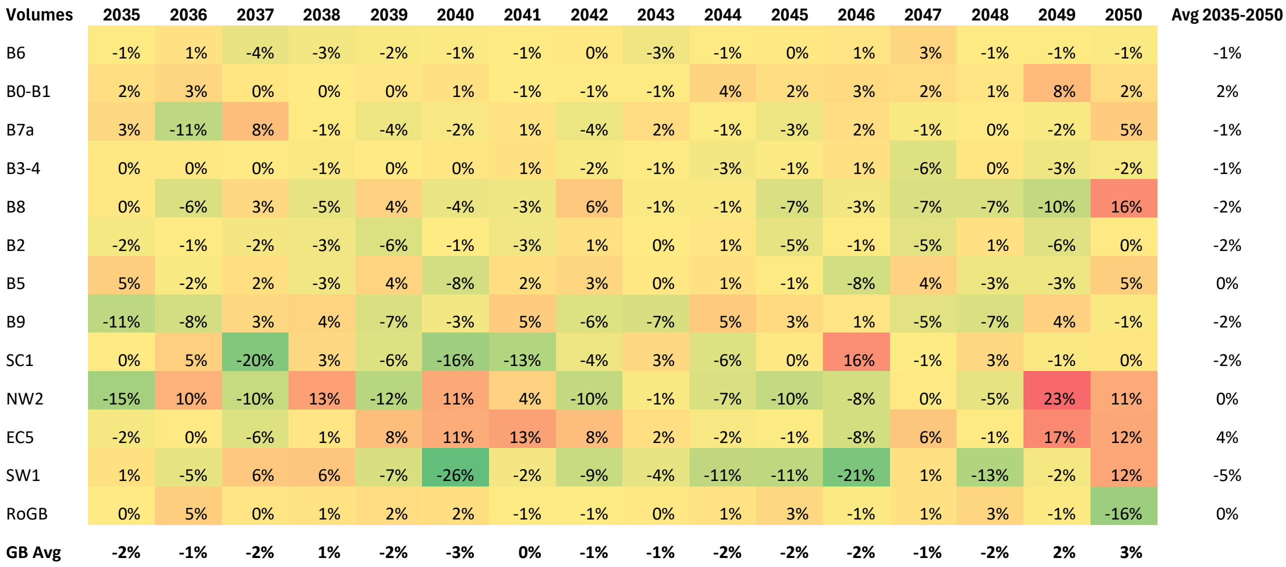
Similarly to the low ambition, these charts show a mixed picture across boundaries and years. Interestingly however, the heatmaps for low and counterfactual do not always show the same trends in the same boundaries and years.

The greatest savings are between 1 and 2%, in B9, SC1, NW2 and SW1, and the greatest increase is 1% in EC5. However, all these boundaries show variance from these trends across different years.

Medium Ambition with Battery Sensitivity:

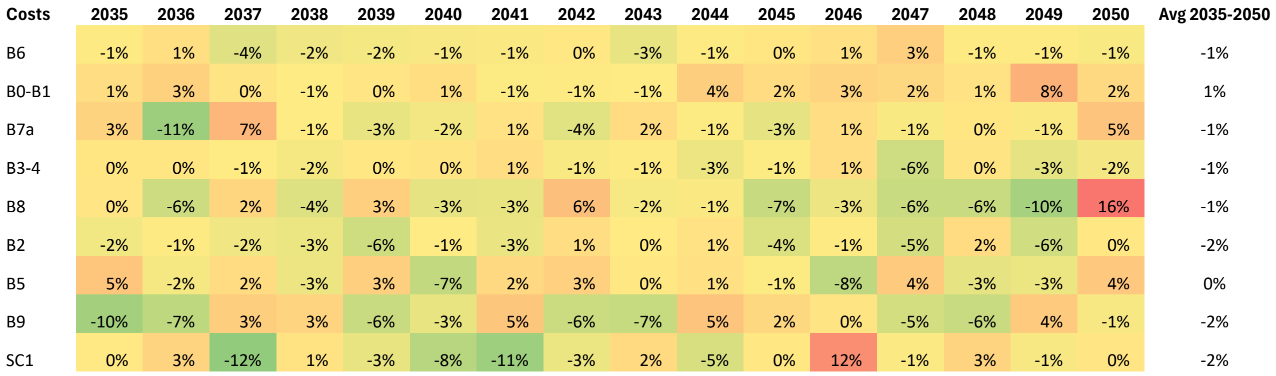
The following two heatmaps show the impact on the constraint and balancing costs and volumes when co-located battery storage is applied to the tidal generation assets in the medium scenario, compared to the medium ambition scenario with no batteries.

Table 2-10: *Constraint and balancing volume percentage change of the medium ambition scenario when including co-located battery storage with each asset compared to no co-located batteries*

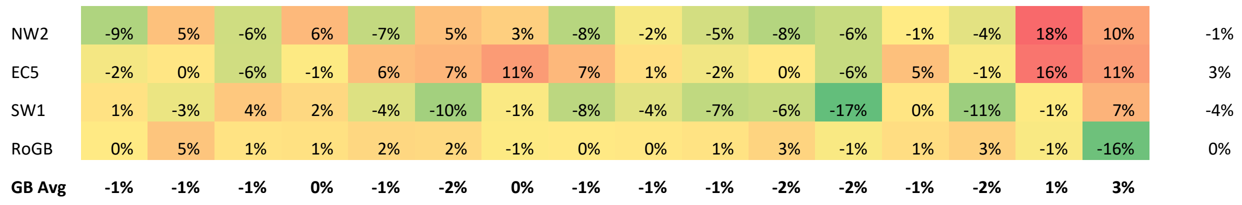


Volumes	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	Avg 2035-2050
B6	-1%	1%	-4%	-3%	-2%	-1%	-1%	0%	-3%	-1%	0%	1%	3%	-1%	-1%	-1%	-1%
B0-B1	2%	3%	0%	0%	0%	1%	-1%	-1%	-1%	4%	2%	3%	2%	1%	8%	2%	2%
B7a	3%	-11%	8%	-1%	-4%	-2%	1%	-4%	2%	-1%	-3%	2%	-1%	0%	-2%	5%	-1%
B3-4	0%	0%	0%	-1%	0%	0%	1%	-2%	-1%	-3%	-1%	1%	-6%	0%	-3%	-2%	-1%
B8	0%	-6%	3%	-5%	4%	-4%	-3%	6%	-1%	-1%	-7%	-3%	-7%	-7%	-10%	16%	-2%
B2	-2%	-1%	-2%	-3%	-6%	-1%	-3%	1%	0%	1%	-5%	-1%	-5%	1%	-6%	0%	-2%
B5	5%	-2%	2%	-3%	4%	-8%	2%	3%	0%	1%	-1%	-8%	4%	-3%	-3%	5%	0%
B9	-11%	-8%	3%	4%	-7%	-3%	5%	-6%	-7%	5%	3%	1%	-5%	-7%	4%	-1%	-2%
SC1	0%	5%	-20%	3%	-6%	-16%	-13%	-4%	3%	-6%	0%	16%	-1%	3%	-1%	0%	-2%
NW2	-15%	10%	-10%	13%	-12%	11%	4%	-10%	-1%	-7%	-10%	-8%	0%	-5%	23%	11%	0%
EC5	-2%	0%	-6%	1%	8%	11%	13%	8%	2%	-2%	-1%	-8%	6%	-1%	17%	12%	4%
SW1	1%	-5%	6%	6%	-7%	-26%	-2%	-9%	-4%	-11%	-11%	-21%	1%	-13%	-2%	12%	-5%
RoGB	0%	5%	0%	1%	2%	2%	-1%	-1%	0%	1%	3%	-1%	1%	3%	-1%	-16%	0%
GB Avg	**-2%**	**-1%**	**-2%**	**1%**	**-2%**	**-3%**	**0%**	**-1%**	**-1%**	**-2%**	**-2%**	**-2%**	**-1%**	**-2%**	**2%**	**3%**	

Table 2-11: *Constraint and balancing cost percentage change of the medium ambition scenario when including co-located battery storage with each asset compared to no co-located batteries*



Costs	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	Avg 2035-2050
B6	-1%	1%	-4%	-2%	-2%	-1%	-1%	0%	-3%	-1%	0%	1%	3%	-1%	-1%	-1%	-1%
B0-B1	1%	3%	0%	-1%	0%	1%	-1%	-1%	-1%	4%	2%	3%	2%	1%	8%	2%	1%
B7a	3%	-11%	7%	-1%	-3%	-2%	1%	-4%	2%	-1%	-3%	1%	-1%	0%	-1%	5%	-1%
B3-4	0%	0%	-1%	-2%	0%	0%	1%	-1%	-1%	-3%	-1%	1%	-6%	0%	-3%	-2%	-1%
B8	0%	-6%	2%	-4%	3%	-3%	-3%	6%	-2%	-1%	-7%	-3%	-6%	-6%	-10%	16%	-1%
B2	-2%	-1%	-2%	-3%	-6%	-1%	-3%	1%	0%	1%	-4%	-1%	-5%	2%	-6%	0%	-2%
B5	5%	-2%	2%	-3%	3%	-7%	2%	3%	0%	1%	-1%	-8%	4%	-3%	-3%	4%	0%
B9	-10%	-7%	3%	3%	-6%	-3%	5%	-6%	-7%	5%	2%	0%	-5%	-6%	4%	-1%	-2%
SC1	0%	3%	-12%	1%	-3%	-8%	-11%	-3%	2%	-5%	0%	12%	-1%	3%	-1%	0%	-2%



NW2	-9%	5%	-6%	6%	-7%	5%	3%	-8%	-2%	-5%	-8%	-6%	-1%	-4%	18%	10%	-1%
EC5	-2%	0%	-6%	-1%	6%	7%	11%	7%	1%	-2%	0%	-6%	5%	-1%	16%	11%	3%
SW1	1%	-3%	4%	2%	-4%	-10%	-1%	-8%	-4%	-7%	-6%	-17%	0%	-11%	-1%	7%	-4%
RoGB	0%	5%	1%	1%	2%	2%	-1%	0%	0%	1%	3%	-1%	1%	3%	-1%	-16%	0%
GB Avg	**-1%**	**-1%**	**-1%**	**0%**	**-1%**	**-2%**	**0%**	**-1%**	**-1%**	**-1%**	**-2%**	**-2%**	**-1%**	**-2%**	**1%**	**3%**	

Table 2-10 and Table 2-11 show the impact of including a co-located battery with each asset in the medium ambition scenario on the constraint and balancing costs at each boundary. Similarly to the other scenarios the visible impacts are mixed, with different boundaries experiencing both positive and negative impacts on constraint and balancing costs, with the overall picture showing minor reductions in total constraint and balancing costs of approximately 1% for this sensitivity.

*Although the high ambition scenario is shown as having lower constraint and balancing volumes than the medium ambition, this can be attributed to inherent model uncertainties and rounding, rather than suggesting that additional tidal range generation capacity would meaningfully reduce thermal constraint costs over the system.

Table 2-12: *Summary table - Total constraint and balancing volume for each scenario across a common time period.*

Scenario	**GB Power System Constraint and Balancing Curtailment Volume 2037-2050 in TWh**
Counterfactual	578
Low ambition	578
Medium ambition	579
Medium ambition (with BESS)	577
High ambition	578*

2.3.3 Thermal Constraint and Energy Balancing – Boundary Level

This section is investigating specific boundaries to gain a more nuanced picture of how the constraint and balancing costs and volumes are changing at different geographic locations in the different scenarios. It investigates the boundaries where significant volumes of tidal range energy are brought online – B8 and SW1.

Figure 2-12 shows how the curtailment volume behind boundary SW1 changes over the study period depending on the scenario. It shows that the scenarios all follow the same general trend, but that there are some variations between the scenarios. When there are peaks in the constraints, such as in 2044 and 2049, the medium ambition has the highest level of curtailment. The counterfactual, where there is no tidal range generation, tends to be in the middle of the scenarios in terms of curtailment volume.

Figure 2-12: *SW1 Boundary thermal constraint & energy balancing curtailment volumes*

Boundary B8 shows significantly higher levels of curtailment volumes than SW1 due to thermal constraints and energy balancing. Similarly, the counterfactual is typically in the middle of the scenarios, with the high ambition scenario showing the greatest oscillation between peaks and troughs.

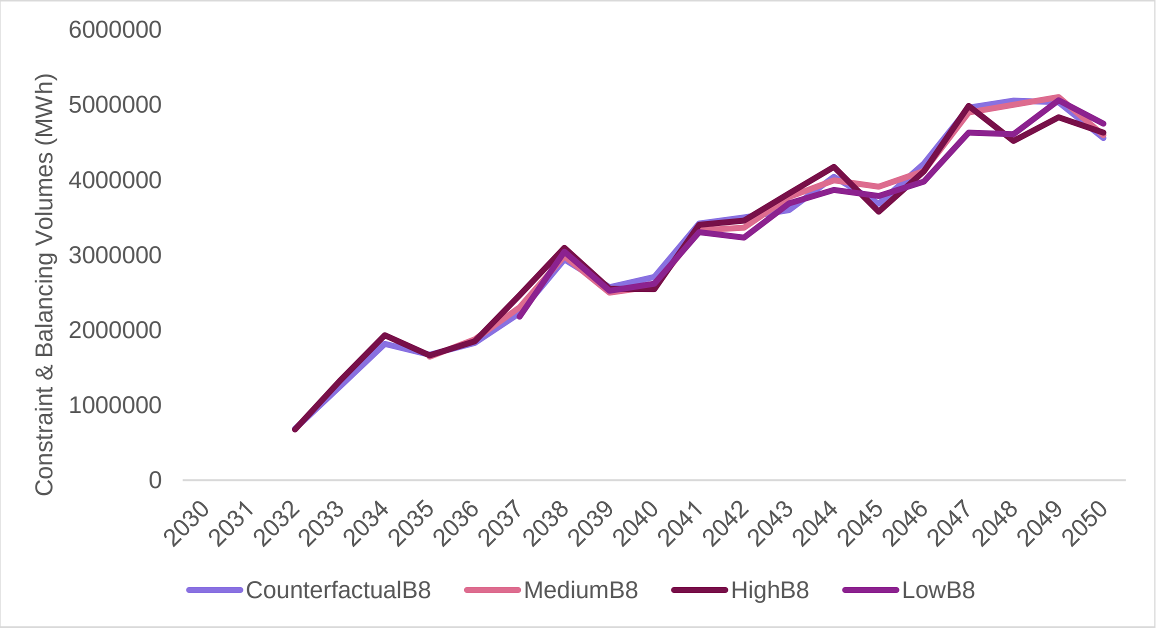


Figure 2-13: *B8 Boundary thermal constraint & energy balancing curtailment volumes*

These two graphs mirror the heatmaps, in that they don't show any consistent trends or patterns, except to demonstrate that bringing more tidal range generation online, where it might be expected that the additional non-dispatchable generation to increase the thermal constraints compared to the counterfactual, seems to have minimal impact.

2.3.4 Thermal Constraint and Energy Balancing - summary

- The study indicates that the level of curtailment due to thermal constraints and energy balancing is not obviously impacted by bringing online more tidal range generation in the modelled scenarios.
- The boundaries with the most generation input, SW1 and B8, show similar trends to the national picture.
- There is no simple linear relationship between tidal generation and the volume of thermal constraint where the tidal generator is located. The ultimate market outcome is a function of the tidal generation with respect to the boundary transmission capacity, generation mix of the boundary as well the market dynamics in the wider transmission network.
- The study indicates that pairing tidal generators with on-site battery storage would let them operate as flexible, dispatchable hybrid generators, cutting the total volume of thermal constraints in most of the boundaries compared to the medium scenario, however only by a relatively small amount. It is important to note that this assessment does not consider the capital cost of the batteries, nor any subsidy that co-located batteries might require.

2.3.5 Wholesale Market Costs – national picture

This section discusses the change in the wholesale market cost of electricity as a result of changing the scenarios, and what is contributing to this change.

When considering this section, as mentioned previously, it should be noted that these results are only using one set of market conditions – the Hydrogen Evolution pathway from FES 2024, and do not account for any electricity market changes that may take place after the conclusion of this study. As previously mentioned, the only change between the scenarios is bringing more tidal range generators online and the timescales of their rollout, there has been no background replacement mix included to account for the tidal range generation that has been removed from the FES 2024 pathway in the low ambition and counterfactual scenarios.

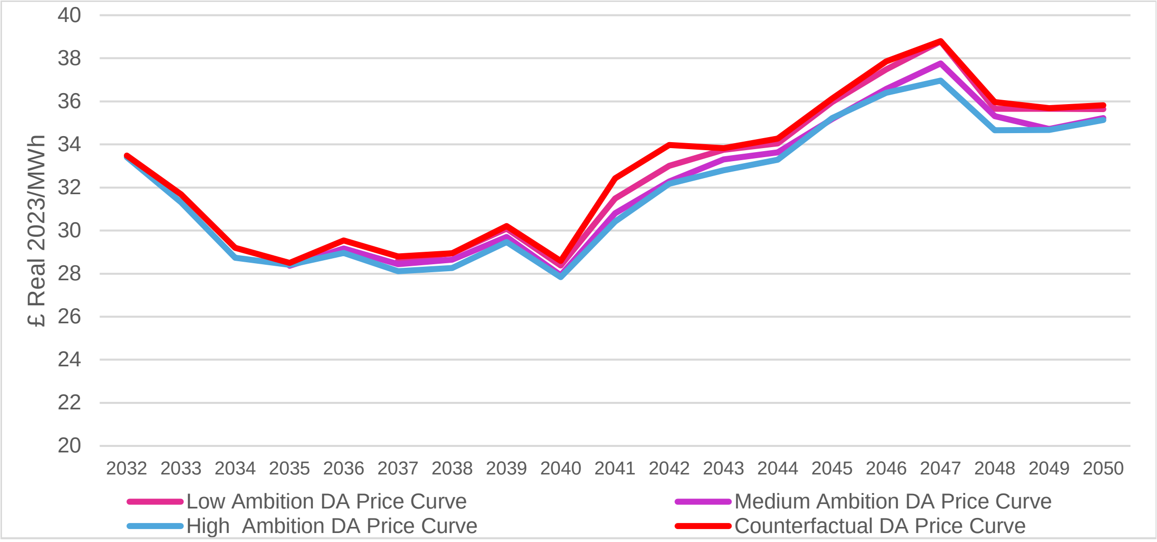


Figure 2-14: *Wholesale day ahead market price forecasts comparing the four scenarios*

Figure 2-14 shows the average day-ahead price annually for each scenario across the study period.

For each scenario, the additional tidal capacity shows a small decrease in the average day ahead baseload price by between £0.25/MWh and £0.60/MWh, which would be expected when additional zero marginal price generation is brought online. The savings from 2040 onward are starker than earlier in the study, which reflects a period where all four scenarios are showing a general increase.

Figure 2-15 shows the change in capacity factor for different generation technologies in the energy mix from the medium ambition to the counterfactual scenario for the year 2050. In practice when tidal range generation is taken out of the generation mix, this shows which generation technologies have to work harder to make up for this reduction in capacity.

This shows that interconnectors are having the greatest increase in their capacity factor, meaning that additional electricity is having to be imported to the UK to make up for the reduction in capacity. This is alongside an increase in demand side response, and an increase in the capacity factor for combined cycle gas turbines with CCUS, Energy from Waste, and other technologies in smaller percentages.

The reduction in tidal range energy generation also sees a reduction in battery storage capacity factor, which suggests that this technology is well suited to maximising the efficiency of battery storage, which is coherent with understanding of the nature of tidal range generation as regular but not dispatchable.

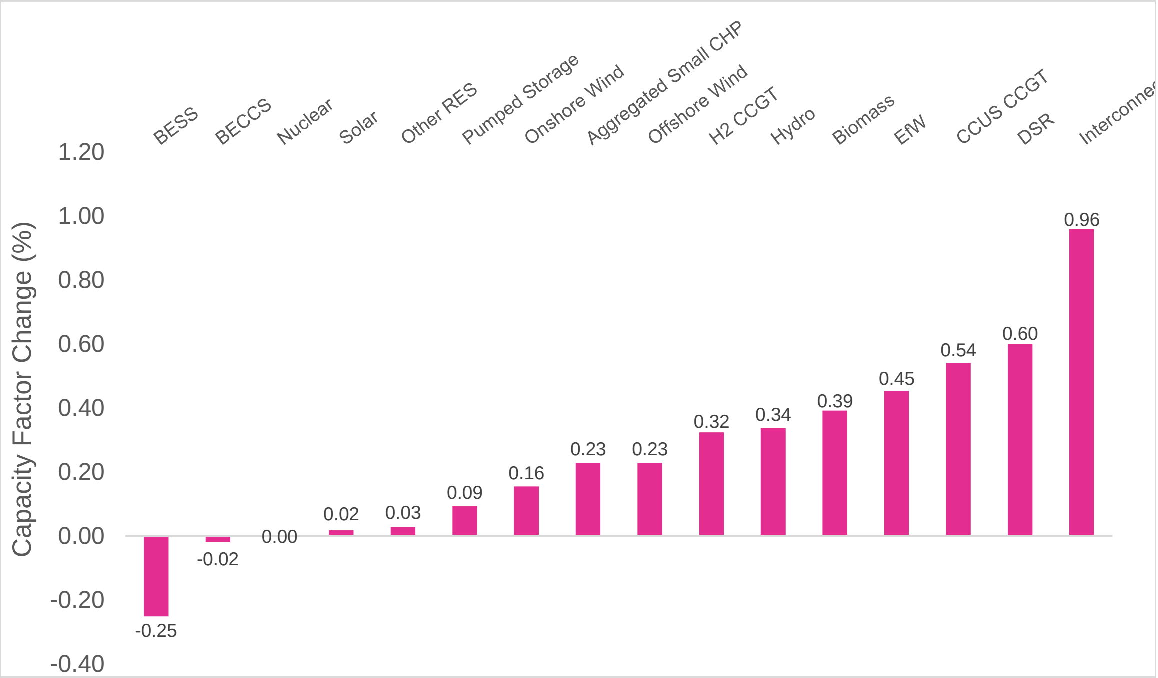


Figure 2-15: *Capacity factor changes in the counterfactual compared to the medium ambition scenario for other generation technologies (2049)*

2.3.6 Sensitivity – replacement capacity mix

The wholesale market cost outputs of the study are sensitive to the replacement capacity mix when tidal range generation is removed from the FES 2024 Hydrogen Evolution pathway.

When the capacity mix for the counterfactual and low ambition scenarios were run with a pro rata mix of the other low carbon generating technologies, the wholesale market prices for these scenarios saw an increase. The reason for this increase is likely to be due to an increase in expensive plant such as CCUS CCGT, biomass and EfW, and more hours in which this plant is price-setting.

Although this sensitivity has the benefit of comparing scenarios with the same total generation capacity, it means that the price changes that can be seen can't be attributed solely to the impact of bring tidal range generation online.

2.3.7 Wholesale market costs summary

The lower day-ahead baseload price is likely a result of the following:

Large block of new, zero-marginal-cost energy

The additional tidal range energy adds a predictable stream of output at approximately 40% capacity factor, that is available in nearly every tide cycle. The average clearing price falls because more hours are met before the market reaches mid-merit and peaking units.

Fewer hours in which expensive plant is price-setting

The 2050 capacity-factor changes shown in Figure 2-15 show that CCUS CCGT, biomass and EfW all increase slightly in the counterfactual compared to the medium ambition scenario. These units carry fuel and in some cases carbon costs, therefore pulling them out of the marginal position directly lowers the baseload price (baseload price is defined as the average of all the hours in a year).

Smoother residual-demand profile cuts scarcity premiums

Tidal generation is phase-shifted from solar and only partly correlated with wind, meaning they have the potential to fill the system's "demand-after-renewables" troughs. Fewer tight hours mean lower scarcity adders and uplift in the auction.

Merchant RES Ramp Down

Hourly demand minus must-run plant sets a cap on non-dispatchable renewables. When extra tidal range generation pushes the system beyond that cap, the market curtails the £0/MWh sources, merchant wind and solar, knocking their 2050 capacity factors. Because all these resources bid at £0/MWh, this curtailment does not contribute to the day-ahead power curve to be lower than the counterfactual scenario.

2.3.8 Carbon Emissions

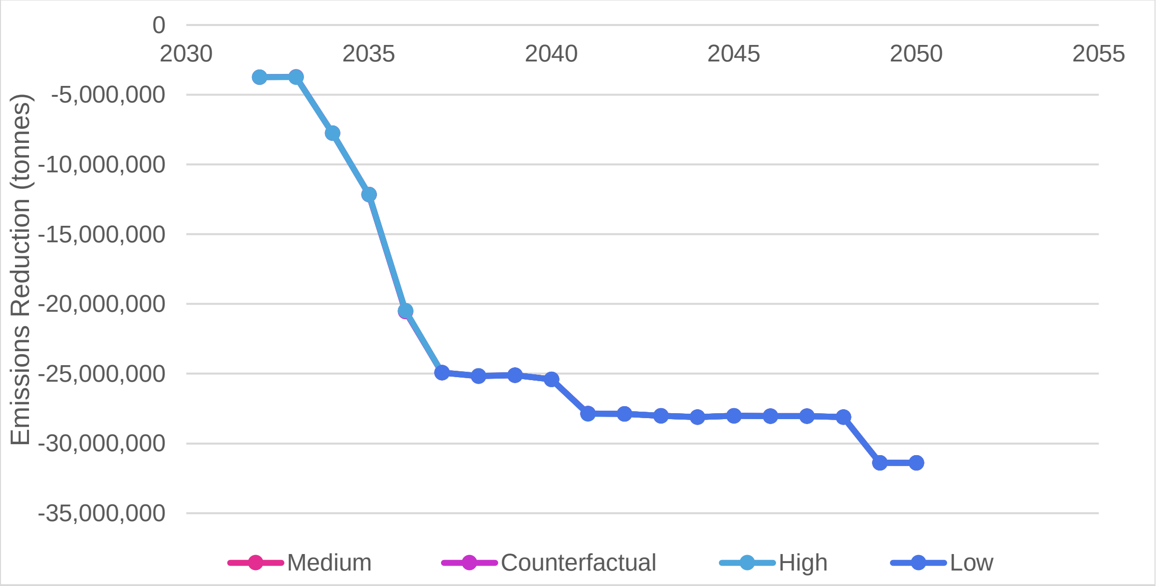


Figure 2-16: *System emissions reduction over study period for each scenario*

The four scenarios are almost indistinguishable on a carbon-reduction basis. Once the system becomes net-negative, the marginal megawatt is supplied almost exclusively by CCUS-equipped or hydrogen-fuelled plant. Adding tidal capacity to the scenarios therefore displaces other zero-carbon options, principally wind, solar and H_2-CCGT rather than fossil generation. Because all of these sources carry a near-zero (or negative) emissions factor, the average system-wide carbon intensity is effectively unchanged. That is why the high, medium and low ambition curves track the counterfactual line so closely throughout the horizon, with any gap well within the uncertainty band of the modelling.

2.3.9 Balancing Services Potential

A high-level, qualitative assessment has been undertaken to understand the potential for tidal range to provide balancing services to NESO, to support the balancing of demand and supply and ensure the security and quality of the electricity supply across Britain's transmission system. This has focussed on three services: inertia, short-circuit capability and reactive power.

Inertia

Inertia in the context of power systems is the kinetic energy stored in rotating masses of synchronous generators. Power systems with significant thermal generation benefit from reduced system stability requirements because thermal generators offer 'inertia'. This means that the turbines continue to spin and produce power even after shutting down, utilising stored kinetic energy that helps slow down the rate of frequency change (Rate of Change of Frequency), when there is a sudden loss of generation or demand.

As the UK moves away from fossil fuels, the resilience of the GB power network is affected because of the loss of thermal generation which offers an inherent resilience through the 'inertia' provided by spinning. Consequently, there is a need for the NESO to procure stability services to help guard against sudden losses causing blackouts. As of 2025, NESO has indicated a minimum system inertia requirement of approximately 120 GVA.s, with a target to reduce this further to 102 GVA.s as new frequency response services and grid-forming technologies are deployed[15].

NESO has sought to secure inertia from other sources via the Network Options Assessment (NOA) Stability Pathfinder project and actions in the Balancing Mechanism. This has been superseded by the Stability Network Services market developed on the back of the original pathfinder projects to procure inertia via short (D-1), mid-term (Y-1), and long-term (Y-4) markets. Two mid-term tenders have been held to date with the first long-term tender launched in March 2025.

Whilst tidal range energy generation uses potential rather than kinetic energy, the potential energy is converted to kinetic energy via turbines, creating a similar spinning affect to thermal generation. Synchronous Alternating Current (AC) connection of tidal power plants to the rest of the grid will therefore produce inertia, helping to slow the rate of frequency change following a disturbance, aiding system stability. Whilst synchronous connection would be a project level decision made by developers, this highlights that tidal range projects have the potential to reduce the costs of maintaining system stability for the system operator by providing inertia and reducing the need for the NESO to procure inertia related services.

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[15] *Frequency Risk and Control Report (FRCR) | National Energy System Operator*

This is likely to offer increased grid stability, with an associated potential cost saving. It should be noted that the scale of these impacts is in the millions and not the billions associated with constraint costs, as well as increased grid stability. The larger the capacity of a tidal range project the greater the benefit through more system inertia and the reduced need for spendings on frequency support by the NESO.

Short circuit capability

Short Circuit Level (SCL) is the amount of current that flows on the electricity system during a fault, which, for example, may be caused by lightning strike, weather or equipment failure. SCL helps maintain system voltage during a fault. NESO's network protection on the transmission system relies on the large current flowing in the system during a fault, registering these large currents and opening circuit breakers to protect the system and equipment.

A system with high SCL is more resilient to disturbances and will recover from a fault quicker than a system without. When SCL is lower, any voltage changes can lead to bigger disturbances that travel further, and if not addressed, could potentially trip generators and/or lead to an unsafe and unstable system, which could damage equipment. Systems with lower SCL may lead to NESO's network protection missing a fault and it will take longer for voltage levels to recover.

The phase out of coal generation combined with increased renewable generation such as wind and solar has contributed to lower SCL on the system, which in turn can create system operability challenges. Historically, NESO had access to the required level of SCL, however, shortfalls are now occurring in certain areas of the electricity system due to the aforementioned phase out of coal and deployment of renewables at scale. NESO needs to increase the number of technologies that can provide SCL, such as additional synchronous condensers, batteries or renewable devices with grid forming inverters.

NESO has sought to secure SCL from other sources and artificially inject into the grid via the Network Options Assessment (NOA) Stability Pathfinder project and actions in the Balancing Mechanism. Going forward, NESO will use the Stability Network Services market to procure SCL and inertia via short (D-1), mid-term (Y-1), and long-term (Y-4) markets. The initial two mid-term tenders have focused on the procurement of inertia, however, SCL may be procured going forward. The first long-term tender was launched in March 2025.

The table below identifies the regions where proposed solutions providing SCL would need to be located and connected to the network. Tidal range assets using synchronous turbine generators have the potential to provide short circuit current, aiding SCL. Those assets located in areas where there are SCL shortfalls, such as in the Severn Estuary and Humber, would reduce the need for NESO to procure additional SCL to address such shortfalls, reducing system costs and ultimately cost to the consumer.

Reference Node	Region	Requirement (MVA)
Lackenby 400kV	North East England	1100
Creyke Beck 400kV	North East England	5400
Minety 400kV	South Wales and West England	250
Seabank 400kV	South Wales and West England	6050
Exeter Main 400kV	South West England	2050
Indian Queens 400kV	South West England	1000
Richborough 400kV	South East England	1100
Glenglass 132kV	South West Scotland	500
Tealing 132kV	East Scotland	700
Peterhead 400kV	North East Scotland	7100
Spittal 275kV	North Scotland	2700
Spittal 400kV	North Scotland	3700

Figure 2-17: *Regions where providing SCL would need to be located*

Reactive Power

Reactive power is essential for maintaining voltage levels within safe limits across the GB transmission network. It arises from the production of electric and magnetic fields in an alternating current (AC) system. Unlike active power, which performs useful work, reactive power does not transfer energy but is crucial for voltage control. NESO manages voltage by instructing generators and other asset owners to either absorb or inject reactive power as needed, ensuring voltage levels on the system remain within a given range, as mandated in the Security and Quality of Supply Standard, to maintain the stability and efficiency of the power system.

Tidal range projects that employ synchronous turbine generators will be capable of absorbing or injecting reactive power aiding grid stability. Further, as a grid code obligation, generators are required to provide a minimum level of reactive power to support voltage stability, therefore provision is mandatory. In addition, NESO tenders for additional reactive power capability to secure extra support for voltage control. Previously this was via the long-term voltage pathfinders but is now secured via short (D-1), mid-term (Y-1), and long-term (Y-4) markets as is the case for inertia and SCL.

In summary, tidal range projects have the capability to supply inertia, SCL and reactive power when using synchronous turbine generators. The deployment of a tidal range project should therefore benefit grid stability as traditional synchronous generation retires. From a consumer perspective, the inertia, SCL and reactive power supplied by a tidal range project should reduce the costs incurred by NESO, and these savings passed through to consumers in procuring these services, which in turn benefit the CBA. From a tidal range project perspective, there is also the potential that a project could tender to provide some of these services, which, if successful, would provide a further revenue stream in addition to wholesale market sales, improving the financial viability of a project via higher revenues.

3. Commercial Case

Delivery

Interfaces

As discussed in the Economic Case, the scenarios assessed in this study relate to pathways for the possible delivery of tidal range assets in GB. They do not relate to specific projects. Therefore, the commercial case centres around the likely ways in which the scenarios could be delivered, including potential requirements for central government support. There are multiple possible delivery models for each scenario (and individual projects within them), and at this stage these do not have a material effect on the outcomes. This section should not be taken as a recommendation for the proposed rollout of any tidal range generation assets.

3.1 Delivery

3.1.1 Low Ambition

The low ambition scenario is most likely to be delivered on an individual project basis, either carried out by private developers or local authorities. The developer would be responsible for independently developing designs, securing consents, appointing contractors and agreeing the required financing and government subsidies.

In December 2023, the Department for Energy Security and Net Zero (DESNZ) published criteria for a well-developed tidal range proposal[16], under the categories:

- Demonstration of energy system benefits
- Demonstration of credible environmental impact mitigation strategy
- Demonstration of value for money
- Demonstration of socio-economic impacts and benefits

Developers would need to demonstrate these for each project, working with the organisations listed in 3.2, in particular around energy system benefits, environmental impact mitigation and end of life strategy. It is also less likely that a RAB financing mechanism would be implemented for private developer led proposals.

A piecemeal approach with little or no strategic direction risks losing the benefits of lessons being shared between projects, and makes a competitive market less likely, reducing the opportunity for increased benefits and cost savings.

As highlighted in Table 2-2, the need for these tasks to be delivered independently results in the two projects included in this scenario being delivered later than in the medium and higher ambition. This has been evidenced by ongoing and proposed projects. Tidal Lagoon Swansea Bay (TLSB) took around three years to secure planning permission via a Development Consent Order[17], and if successful would have been delivered in a further five

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[16] *https://www.gov.uk/government/publications/tidal-range-projects-criteria-and-how-to-submit-a-proposal/criteria-for-a-well-developed-tidal-range-proposal*
[17] *https://www.bbc.co.uk/news/uk-wales-south-west-wales-44589083*

to seven years. The projects considered in this scenario have a larger capacity than was proposed at TLSB, and so assume a longer total time than this to deliver.

3.1.2 Medium Ambition

A medium ambition scenario involves both speeding up delivery of the proposed locations in the low ambition scenario, and the delivery of additional tidal range generation assets around GB. For this case, development of the projects could be by project developers, but is likely to require government support such as:

- A National Policy Statement where specific sites are designated as being suitable for development, and providing certainty to developers and the supply chain
- Supply chain investment in construction of key components such as caissons, turbines and marine infrastructure
- Investment in research, site selection, initial development and surveys, leading to a competitive tender process for development
- A strategic approach to environmental mitigation and compensation delivery
- Collating lessons learned and innovations from projects to apply to future schemes and reduce costs.

Both the Hendry Review[18] and Severn Estuary Commission[19] included recommendations for increased government support, and the use of a demonstrator or 'pathfinder' project that would lead to a wider project roll-out across the UK if successful.

Increased support could foster a more joined-up approach to the delivery of multiple assets and would allow consistency in many of the assessments required for a 'well-developed tidal range proposal'. For example, this study has investigated the energy system impacts of generic tidal lagoon projects, but could be built upon for more specific proposals as they become available.

This approach is also likely to lead to more genuine competition at specific sites to drive innovation and reduce costs, as has been seen in other renewable industries.

3.1.3 High Ambition

It is recognised that the high ambition scenario would require a significant departure from how renewable energy projects have been delivered in GB in the past. The number of projects to be delivered and proposed timescales would require a central, joined-up approach to project delivery which would likely require significant government backing. In addition to the measures proposed in the medium ambition scenario, this could require:

- Specific, reformed planning and consenting processes
- Direct investment

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[18] *Hendry Review – The website for the independent review of tidal lagoons, led by Charles Hendry*

[19] *https://www.severncommission.co.uk/final-recommendations/*

- Development and / or capital investment

As mentioned in Section 2.1, this scenario was included as an ‘upper bound’ of the possible delivery of tidal range assets in GB, and implementing it would present significant challenges. Given the limited benefits over the other scenarios discussed in the CBA results, the commercial case has not been considered further.

3.2 Interfaces

The development of any of the scenarios defined in the study and any subsequent projects arising from them will require the management of interfaces at a national, regional and local level depending on the chosen locations. These could include:

- Central government departments and agencies
- Statutory and non-statutory environmental bodies
- Developers
- Key supply chain and industry organisations
- The Crown Estate and any other relevant landowners
- Great British Energy

This study was commissioned by the National Energy System Operator (NESO). NESO is an independent system planner and operator, helping accelerate Great Britain’s energy transition. Its role in strategic planning is to take a strategic long-term approach and ensuring that the energy system can be designed and built accordingly.

NESO’s three primary duties are:

- Net zero: Enabling the government to deliver on its legally binding emissions targets
- Efficiency and economy: Promoting efficient, coordinated and economical systems for electricity and gas
- Security of supply: Ensuring security of supply for current and future consumers of electricity and gases.

NESO also consider the creation and maintenance of competitive energy markets; impact on consumer and the whole energy system and how to facilitate innovation.

In this context, the business case presented here is strongly aligned with NESO’s primary and secondary duties. It increases the understanding of how tidal range energy (an innovative technology in itself) impacts on consumers and the whole energy system, and what role it could play in driving forward net zero and a secure energy supply.

4. Financial Case

- Generation Asset Cost Build-Up
- LCOE and Required Subsidy Cost
- Revenues
- CfD Scheme Costs
- CBA Results and Discussion

The financial case is a summary of the affordability of the proposed scenarios. To interpret the affordability the costing techniques for the analysis is explained, and then a comparison between RAB and traditional non-regulated LCOE is detailed and discussed.

4.1 Generation Asset Cost Build-Up

The delivery costs for each specific asset are developed by the Arup Tidal Tool (ATT) using bottom-up costing based on the following components:

- Design and supervision
- Preliminaries (pre-construction contractor costs)
- Impoundment bund
- Lagoon powerhouse (includes turbine house civils, sluice caisson, dredging and sluice gate)
- Turbines and turbine replacement costs
- Grid connection infrastructure
- Construction / site facilities

Figure 4-1 and Figure 4-2 show the typical breakdown of these components in the total cost with and without optimism bias (see key assumptions)

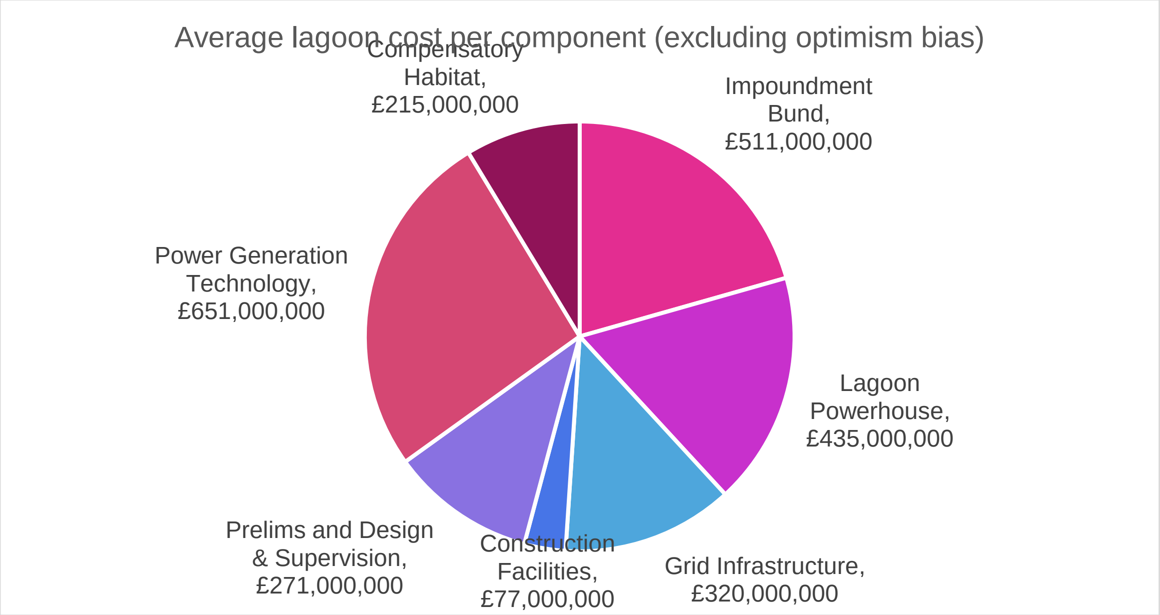

Figure 4-1: *Breakdown costs per component averaged across the tidal range generation assets, excluding optimism bias*

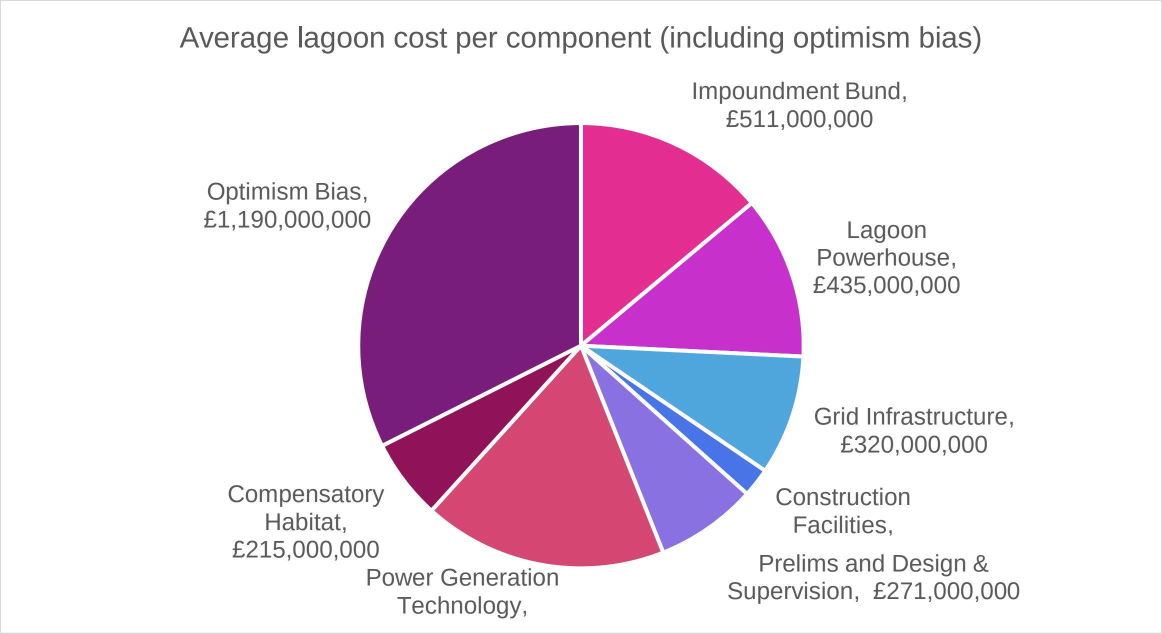

Figure 4-2: *Breakdown costs per component averaged across the tidal range generation assets, including optimism bias*

Key costing assumptions

2023 prices – All costing has been done using 2023 real prices.

Compensatory habitats – As there are no examples of real projects to understand the estimated costs of compensatory habitat creation and maintenance, an assumption of 10% of the total construction cost has been applied to each asset. This has been based off Arup's internal expertise and a high-level review of publicly available information on offshore infrastructure suggesting 1-5% of CAPEX as a typical figure for compensatory habitat cost.

Preliminaries – These include pre-construction costs that would be required by contractors. It is assumed that turbines and associated equipment would be manufactured and delivered by suppliers ready to install and therefore those costs are inclusive of preliminaries. For all other categories preliminaries are estimated at 12% of the component cost, based on Arup internal review of infrastructure projects.

Design & supervision – These costs are calculated using a percentage for each cost component varying depending on complexity.

Grid connection – Costs are estimated for grid connection infrastructure, based on offshore substation, seaward cable routes, overland cable routes and substation works.

Optimism bias – This has been developed using government's Green Book Guidance[20], with tidal range generation assets assumed to be a 'Non-Standard Civil Engineering project'. Using this guidance, the upper bound starting position for Optimism Bias for these projects is 66%, has been reduced to 55% for this project for the following reasons:

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[20] *Supplementary Green Book Guidance – Optimism Bias, Microsoft Word - GreenBook_optimism_bias.doc*

- Environmental impact has already been considered by the high figure for compensatory habitats.
- Technology has been removed due to tidal range schemes not requiring any new or innovative technology specifically (although as a whole project they are innovative, therefore degree of innovation remains at upper bound).
- Design complexity (8%) will be halved to 4%, to reflect that the components of a tidal range lagoon are typical civil engineering works (breakwater style wall, concrete caissons etc).

To carry out calculations to determine the LCOE of tidal range assets, which is used to determine the required subsidy, the above costs have been sorted into the following categories:

- **DEVEX** – The DEVEX costs included design and supervision and preliminaries.
- **CAPEX** – The CAPEX cost includes the lagoon powerhouse, turbines, grid connection infrastructure and construction / site facilities.
- **O&M** – Operation and Maintenance (O&M) costs are yearly costs calculated by multiplying a set amount by the capacity of the lagoon (MW).
- **REPEX** – The REPEX costs are included to represent the cost of replacing the turbine technology, to be applied at 60 years into the operating life of the asset.

4.2 LCOE and Required Subsidy Cost

To calculate the required subsidy cost for each tidal generation asset to include in the CBA, an average cost of the scheme per MWh is required as an input, along with the forecast revenue and hourly generation for each asset.

$$Hourly\ subsidy\ requirement = (Hourly\ revenue * Hourly\ generation) - Cost/MWh$$

$$Total\ subsidy\ requirement = \sum_{0}^{Study\ period} Hourly\ subsidy\ requirement$$

There are growing calls from the tidal range industry for government to consider a RAB funding mechanism.

Non-regulated Levelised Cost of Energy (LCOE) is a measure of the average cost to produce electricity over the lifetime of a power plant, including all costs like construction, operation, and maintenance, divided by the total electricity generated. It is used to compare the cost-effectiveness of different energy sources without any government intervention or subsidies, and uses a net present value calculation to reflect how the value of capital changes over the lifetime of a project.

On the other hand, the **Regulated Asset Base (RAB)** model is used for financing large infrastructure projects. In this model, investors are guaranteed a return on their investment through regulated charges on consumer bills. This means that the financial risk is shared between the investors and the consumers, making it more attractive for private investors to fund public projects like energy infrastructure, and allows the long lifetime of the asset to be accounted for in the cost of financing.

Therefore, this study used both techniques to compare, alongside varying the cost of capital

4.2.1 Non-Regulated LCOE

The LCOE was estimated following a similar method to that specified by DESNZ in their Example LCOE calculation spreadsheet available on the government website[21]. The costs of each asset, grouped into Pre-development (Devex), Construction costs (Capex), and O&M were allocated to appropriate years with an assumed project and generation start date, and an annual generation calculated using the ATT. The assumed hurdle rate has been varied to understand the impact on the conclusions, from 8.3%, which was the hurdle rate used when evaluating TLSB in 2015, up to 10.3% to reflect the increase in discounting rates currently being used to evaluate more established technologies including offshore wind[22]. The hurdle rate used sets the annual discounting applied, to all costs and generation, and then calculate an average cost per MWh.

4.2.2 Regulated Asset Base (RAB)

A RAB model has been created, within which a regulatory asset base has been developed which consists of Devex, Capex and Repex, which is then depreciated over a 60-year period using a 1.67% depreciation factor.

Under the RAB model, allowed revenue is received on an annual basis, and can be considered to be the 'cost to consumers'. This allowed revenue is made up of a number of revenue building blocks, including, depreciation (return of capital), the return of capital (WACC), and operational costs. For the purposes of this analysis, depreciation is assumed to be linear, with a 60-year economic asset life. The asset is therefore fully depreciated after the initial 60 years of operation, at which point turbines are replaced and another 60 years of operation is assumed. Varied values have been input as the weighted average cost of capital (WACC), i.e. a required rate of return of between 2.8% and 4.3%, which are in line with observed benchmarks. This is applied to the RAB, resulting in a reducing saw tooth profile. Opex is assumed to be recovered within the year it is incurred (fast money, i.e. is not added to the RAB) and is assumed at a fixed rate per annum in a flat profile.

Current RAB model schemes (for example for nuclear generation) mean cost is added to consumer bills, so there is a risk that additional risk is borne by consumers should it be adopted, although this could be structured differently for future schemes.

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[21] *Electricity generation costs 2023 - GOV.UK*

[22] *Methodology used to set Administrative Strike Prices for CfD Allocation Round 6*

For simplicity, no tax has been assumed which under a typical RAB model constitutes another smaller revenue building block.

4.2.3 Subsidy Cost Requirement

To reflect the high-level cost assessment carried out, averages across similar cost per MWh have been collated into groups, shown in Table 4-1 and Figure 4-3

Table 4-1: *Variation in cost per MWh across the different generation assets, using different financing mechanisms and varying cost of capital*

Generation Asset Location	LCOE (8.3%)	LCOE (9.3%)	LCOE (10.3%)	RAB (2.8%)	RAB (3.55%)	RAB (4.2%)
North West	£319	£367	£418	£105	£117	£129
Severn Estuary	£216	£249	£284	£68	£75	£83
North Wales & South Coast	£377	£434	£494	£121	£135	£149
East Coast	£658	£757	£863	£208	£232	£256

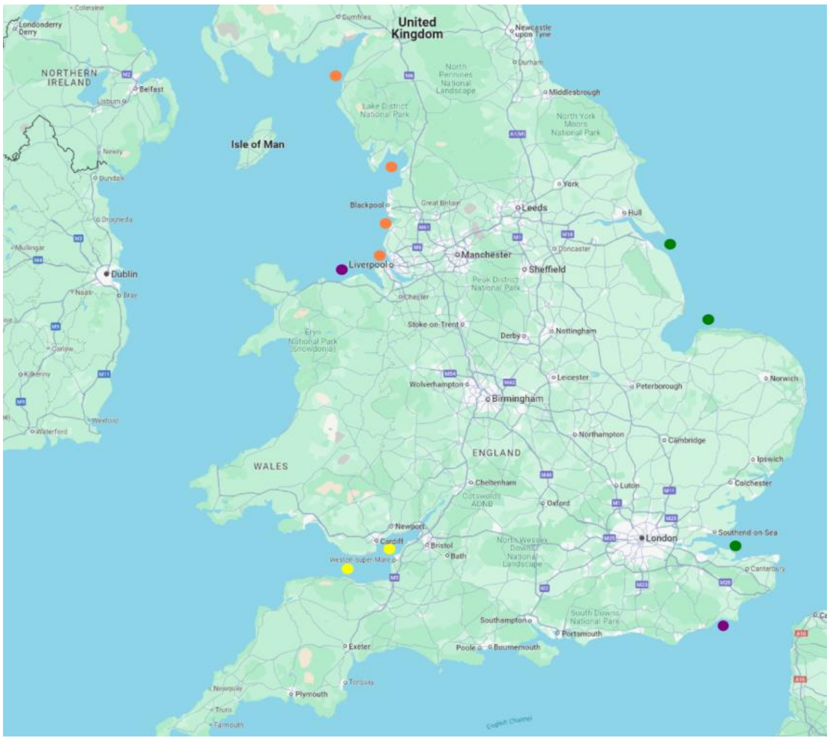


Figure 4-3: *Map showing grouping of generation assets with similar cost per MWh*

The subsidy requirement calculation utilised hourly generation outputs alongside wholesale market cost information from PLEXOS, to calculate an hourly revenue per MWh for each asset. This could then be subtracted from the previously calculated cost per MWh (RAB or non-regulated LCOE) on an hourly basis to estimate what the required subsidy would be and summed to calculate an annual subsidy requirement, which was one of the inputs into the CBA calculation.

4.3 Revenues

This section explores the revenues that assets could potentially generate in the wholesale market. This is then compared to the assumed cost per MWh of the assets, in order to achieve an implied subsidy required for the assets to break even and be economically viable. For simplicity, potential revenues that assets could achieve through ancillary services are not included, however there is a potential for additional ancillary service revenue.

As discussed in the methodology, the scenarios assessed in this study relate to pathways for the possible delivery of tidal range assets in GB. They do not relate to specific projects. Therefore, this analysis centres on the illustration of potential commercial scenarios. The potential revenues in the three scenarios to assess the revenues against costs to achieve an illustration of the implied subsidy have been explored.

4.3.1 Average Annual Revenues and implied subsidy – low ambition

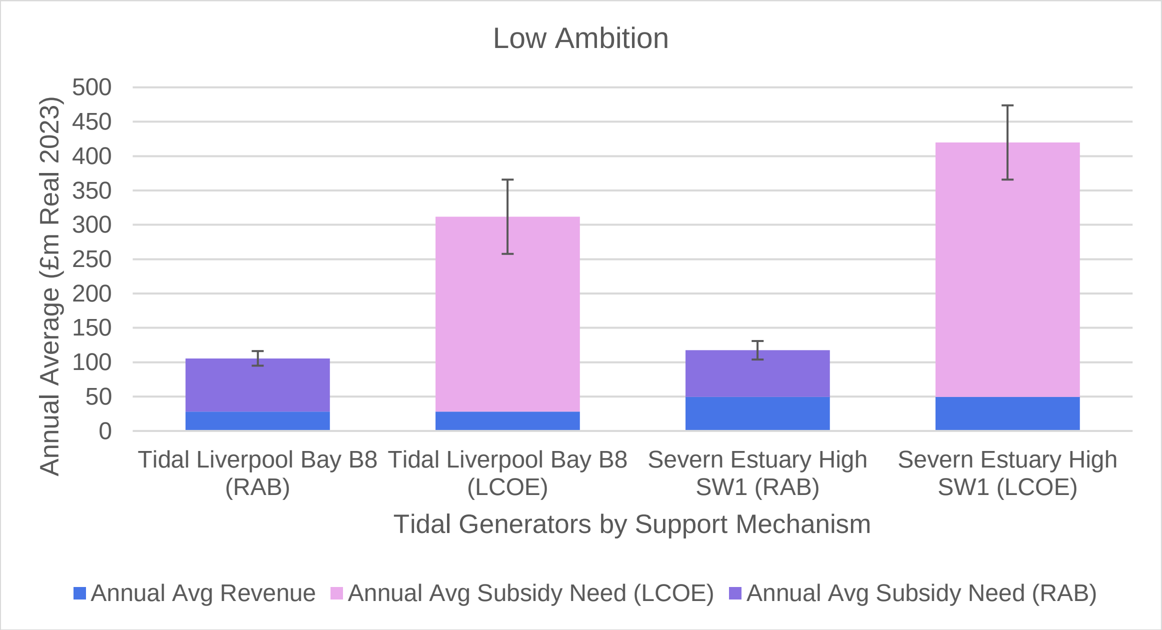


Figure 4-4: *Low Ambition – tidal generators by support mechanism*

Figure 4-4 shows the average annual revenues and implied subsidy for the two tidal assets in the low ambition scenario. Each asset is shown with the varying assumptions of levelised cost and funding mechanisms. The error bars in the chart represent different cost of capital assumptions. The results suggest that in the low ambition scenario the assets would require some form of subsidy to break even. A RAB funding appears to suggest significantly reduced implied subsidy need.

As shown in Figure 4-4 the Severn Estuary High asset generates considerably more average annual revenue than the Liverpool Bay asset. This is because, despite the assets having a similar generating capacity, the tidal range in the Severn is larger than in Liverpool, and so more energy can be generated.

4.3.2 Average Annual Revenues and implied subsidy - medium ambition

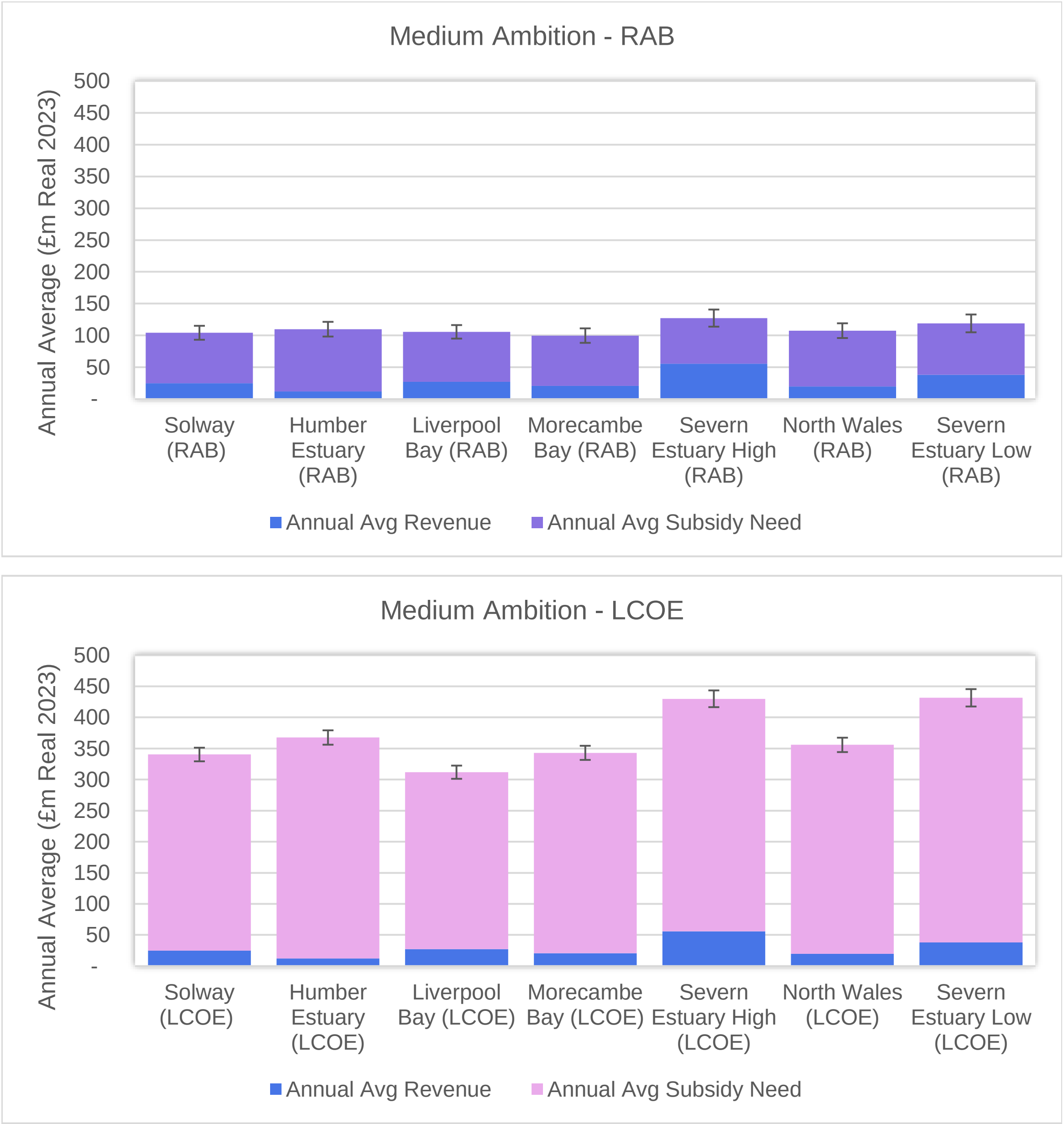


Figure 4-5: *Medium ambition - tidal generators by support mechanism*

The average annual revenues and implied subsidy for each asset under the different LCOE assumptions for the medium ambition scenario is shown in Figure 4-5 above. The results suggest the implied subsidy is slightly higher in the medium ambition scenario than the low ambition for the two common assets (Severn Estuary High and Liverpool Bay). The implied subsidy needs for the newly introduced assets are mostly higher than the two common assets, because of their locations with lower tidal range and thus reduced energy output.

This effect is exacerbated by the tidal assets reducing the revenues of each other, because of their combined dampening of the wholesale price. The sum of the tidal assets has an impact on the wholesale price which in turn significantly reduces revenues. Again, the implied subsidy required is heavily influenced by LCOE assumptions and the funding model.

4.3.3 Average Annual Revenues and implied subsidy - high ambition

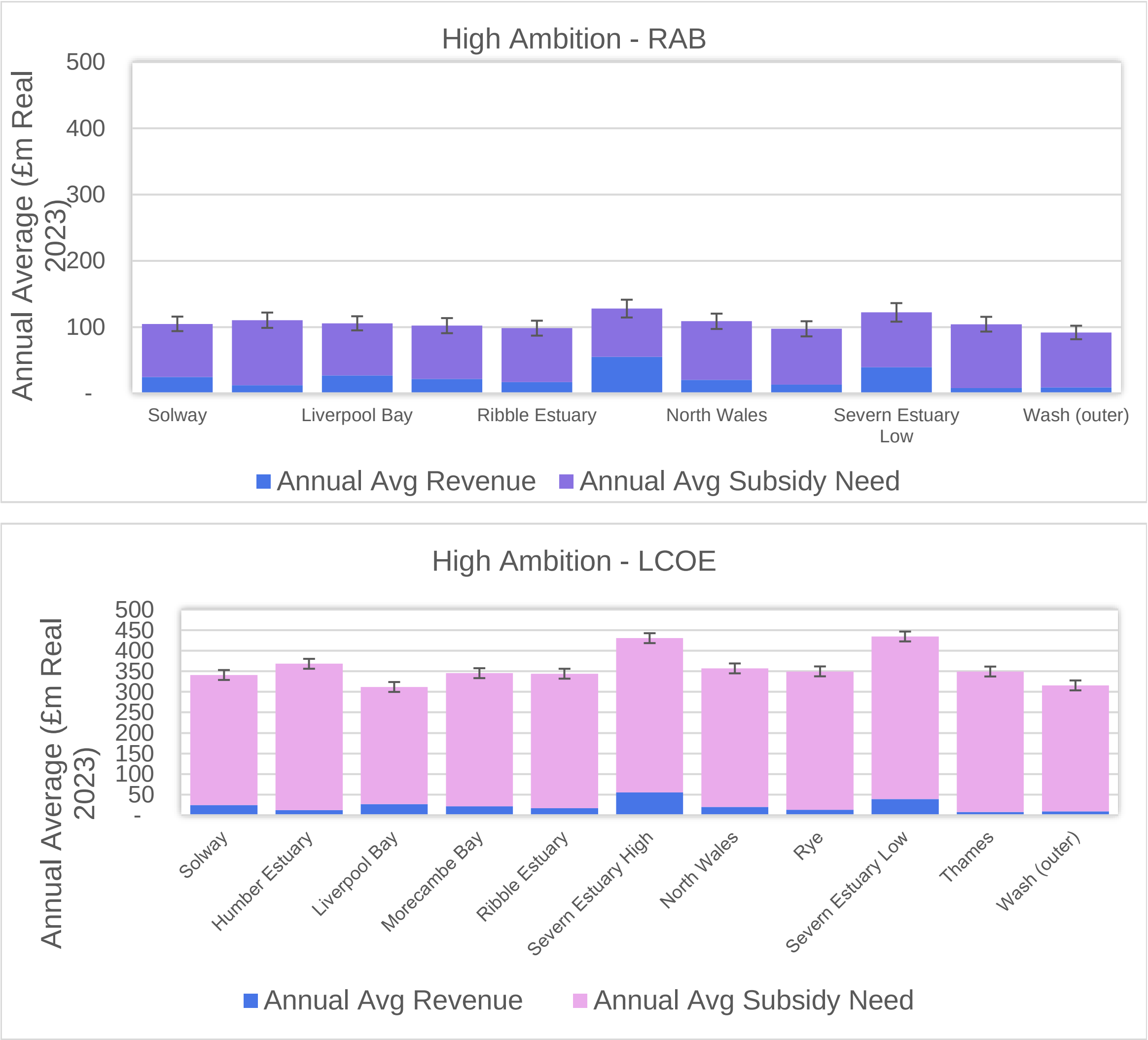


Figure 4-6: *High Ambition - tidal generators by support mechanism*

The high ambition scenario, shown in Figure 4-6 above, produces similar results to the medium ambition, including the subsidy required for individual assets between scenarios. In this case all assets require a significant subsidy support to break even on annual basis. The higher subsidy requirement compared to the low ambition scenario is driven by the impact on the wholesale price of the combined tidal assets reducing revenues of all assets.

The financial case for tidal assets suggests that developers would need some form of subsidy support for the assets to break even. This is not unexpected given the costs of the assets compared to the modelled wholesale price, and noting that subsidies are common in the renewables industry, such as the Contracts for Difference scheme which is widely used in the Offshore Wind sector.

Given the results are sensitive to the wholesale price, further testing of other scenarios is recommended. In addition, the results also indicate the sensitivity of the funding model and LCOE assumptions to the levels of required subsidy.

4.4 CfD Scheme Costs

The final portion of the Cost Benefit Analysis is to understand the changes to existing subsidy agreement costs. This study has only considered CfD costs, as these make up the largest share of subsidies at the time of reporting.

In most of the scenarios, the change in CfD scheme costs roughly balances out the change in whole-sale market costs. This is because when there is a reduction in the wholesale market price being captured by renewable generators that are part of a CfD, the agreement requires the difference between the agreed strike price and the capture price to be paid by government as subsidy.

For the BESS sensitivity analysis, the CfD cost decreases because wind and solar capture prices in the day-ahead market are higher compared to the base medium ambition scenario. This sensitivity allows BESS units on the system to store more energy and charge more aggressively when it is eco-nomically attractive. Typically, this happens when wind and solar output is high, which pushes electricity prices down. By charging during these low-price periods, BESS increases demand, which lifts market prices. This improves the price captured by wind and solar generators, bringing it closer to their CfD strike price. As a result, these generators require smaller top-up payments from the CfD scheme, reducing overall CfD costs.

4.5 CBA Results and Discussion

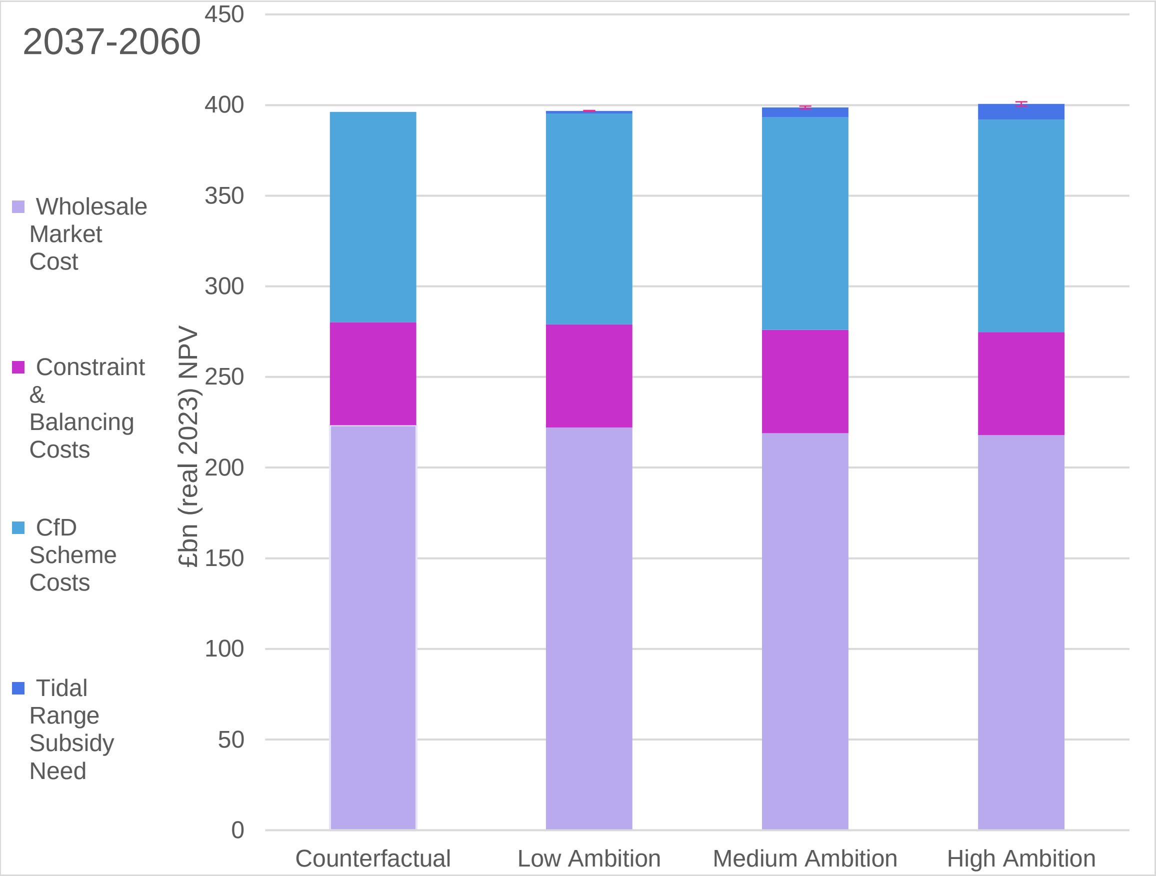
From the individual analyses described in previous sections it is possible to create a cost benefit analysis (CBA) comparing the sum of the wholesale market cost of electricity, the constraint and balancing costs, the knock on CfD scheme costs, and the subsidy requirements for each of the modelled scenarios and compare back to the counterfactual.

These are shown in the following figures, which are intended to reflect total cost to the consumer. Figure 4-7 shows the CBA comparison of the four scenarios where the tidal range subsidy need is calculated using the RAB mechanism, and that there is only a small difference between the four scenarios.

Figure 4-8 shows the LCOE style funding mechanism, and the impact of the financing cost of the schemes, and the error bars indicate the influence of the cost of capital.

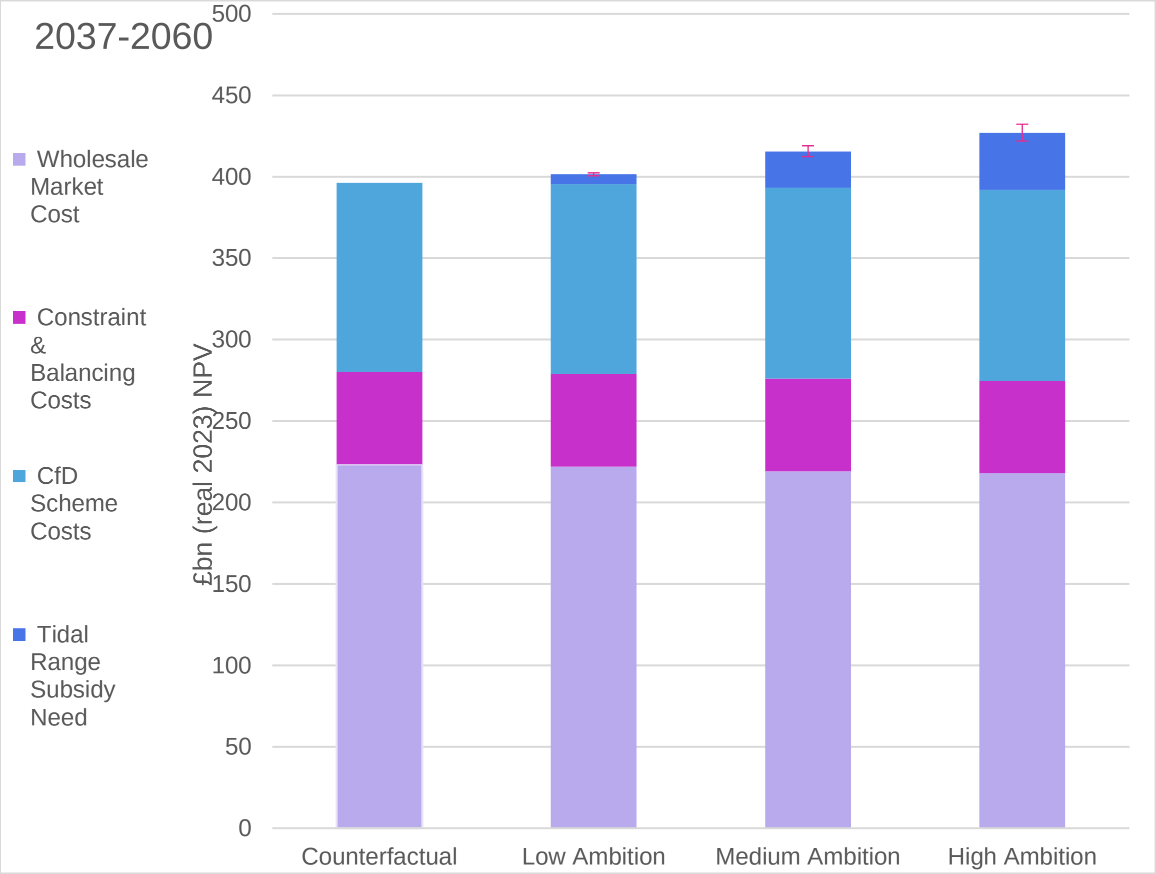
When considering that these results are simply comparing the costs of not having any tidal range on the system to having varying volumes of capacity on the system, and not making up the difference with any replacement technology, it is implicit that there would be a cost impact of installing additional capacity.

This reinforces the result that affordability and value for money is very dependent on the financing mechanisms considered, and comparing that to the cost of alternative ways of reaching Net Zero.



	Counterfactual		Low Ambition		**Medium Ambition**	High Ambition	
Wholesale Market Cost	223	(4)	222	(3)	**219**	218	1
Constraint & Balancing Costs	57	0	57	0	**57**	57	0
CfD Scheme Costs	116	1	116	1	**117**	117	0
Subsidy Need	-	5	1	4	**5**	9	(4)
Total	**396**	**2**	**397**	**2**	**399**	**401**	**(2)**
Number of Assets	0		2		7	11	
Tidal Range Capacity (GW)	0		1.4		5.1	7.8	
Total System Capacity change with respect to the Medium Ambition Scenario (GW)	-5.1		-3.7		0	2.7	

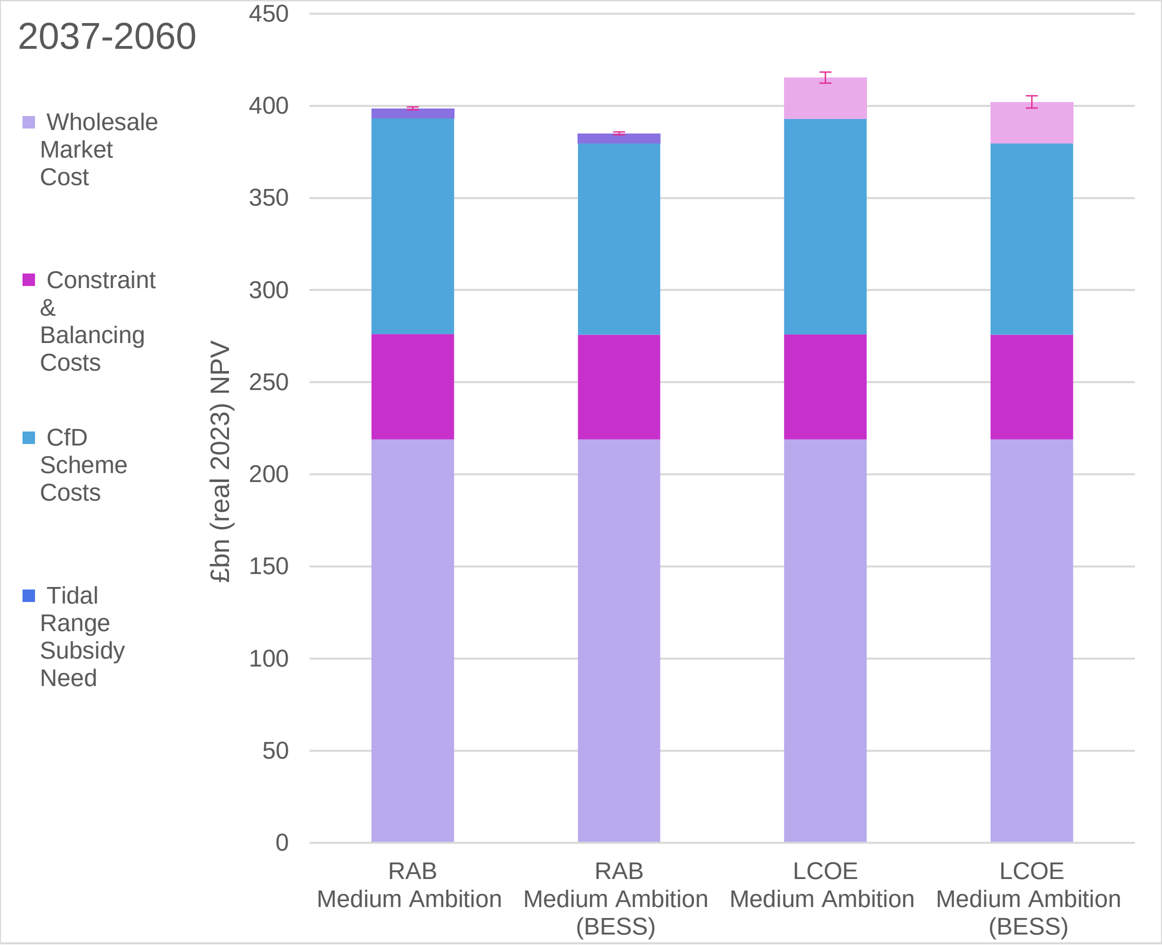
Figure 4-7: *Whole System Cost (£bn) comparison between scenarios (RAB subsidy mechanism) – Note values in red show difference from medium ambition (medium ambition minus scenario). Note totals in the table may not sum due to compounded rounding.*



	Counterfactual		Low Ambition		**Medium Ambition**	High Ambition	
Wholesale Market Cost	223	(4)	222	(3)	**219**	218	1
Constraint & Balancing Costs	57	0	57	0	**57**	57	0
CfD Scheme Costs	116	1	116	1	**117**	117	0
Subsidy Need	-	22	6	16	**22**	35	(13)
Total	**396**	**19**	**401**	**14**	**416**	**427**	**(11)**
Number of Assets	0		2		7	11	
Tidal Range Capacity (GW)	0		1.4		5.1	7.8	
Total System Capacity change with respect to the Medium Ambition Scenario (GW)	-5.1		-3.7		0	2.7	

Figure 4-8: *Whole System Cost (£bn) comparison between scenarios (Non-regulated LCOE calculation). Note values in red show difference from medium ambition (medium ambition minus scenario). Note totals in the table may not sum due to compounded rounding.*

Finally, Figure 4-9 below illustrates the impact of the battery sensitivity analysis on the whole system cost to consumer, indicating that the main impacts are on the CfD subsidy scheme costs, the reasoning for which is discussed in Section 4.4. Unlike the other scenarios, the wholesale market costs do not reflect this change, as they balance out across the annual averaging process. Therefore, even though the impact of the co-located BESS on the constraint and balancing costs is negligible, there could still be a saving to the consumer. Assumptions and limitations of the battery sensitivity tests are given in 2.1.2.



	RAB	**RAB**	**LCOE**	**LCOE**
	Medium Ambition	Medium Ambition (BESS)	Medium Ambition	Medium Ambition (BESS)
Wholesale Market Cost	219	219	219	219
Constraint & Balancing Costs	57	57	57	57
CfD Scheme Costs	117	104	117	104
Subsidy Need	5	5	22	22
Total	**398**	**385**	**415**	**402**

Figure 4-9: *Whole System Cost (£bn) comparison of the battery sensitivity on the medium ambition scenario. (Figures using RAB subsidy mechanism with 3.55% WACC on the left and LCOE subsidy mechanism on the right)*

5. Management Case

Low Ambition

Medium Ambition

High Ambition

Potential for Programme and Budget Reduction

This section considers how each of the scenarios could be delivered, considering the required programme for delivery and how time and cost savings could be achieved.

5.1 Low Ambition

The low ambition scenario considers the development of only two tidal range generation assets, with one in the Severn Estuary and one in North-West England. This scenario represents the lower envelope of ambition and characterises the current status of the tidal range industry and developer interest. It is expected that in this scenario, assets would be developer-led with very limited government intervention to support supply chain capabilities, planning reform or coordination of projects to speed up delivery, and therefore doesn't see the first asset come online until the late 2030s. Each project would independently produce a business case, planning application and other consents (including a DCO, Crown Estate lease agreement and marine licence). Likewise, construction would be carried out through existing supply chain capabilities for key components (such as turbines and bund material) and is likely to have a limited impact on building a specific UK supply chain. The timescales for each stage from development through to construction have been estimated based on publicly available data for previously proposed and existing tidal range schemes and similar coastal engineering projects.

A draft programme is given in Appendix A.1 with key dates below:

Table 5-1: *Low ambition scenario key dates*

Lagoon No.	Location	Task(s) Start Year						
		SOC	**Lease agreement**	**Grid connection and DCO**	**OBC**	**FBC / FID**	**Construction**	**Lagoon online**
1	Liverpool Bay	2026	2027	2027	2028	2029	2032	2037
2	Severn Estuary (High)	2029	2030	2030	2031	2032	2035	2040

5.2 Medium Ambition

The medium ambition scenario represents a more ambitious case, with the development of seven tidal range generation assets coming online between 2035 and 2041. To achieve this, some reductions in task durations would be required. For example, when compared to the low ambition scenario, the time taken for the DCO process has been reduced from 5 to 3.5 years (see 5.4.4). The lagoon construction duration is also reduced from 5 to 4 years. Some investment in supply chain would likely be required to realise this, (for example a turbine fabricating facility in the UK), as well as some of the support mechanisms mentioned in 3.1.2 and construction techniques in 5.4.6.

A draft programme is given in Appendix A.2 with key dates below:

Table 5-2: *Medium ambition scenario key dates*

Lagoon No.	Location	Task(s) Start Year						
		SOC	**Lease agreement**	**Grid connection and DCO**	**OBC**	**FBC / FID**	**Construction**	**Lagoon online**
1	Liverpool Bay	2028	2028	2028	2028	2030	2032	2035
2	Severn Estuary (High)	2029	2029	2029	2029	2031	2033	2036
3	Solway	2029	2030	2030	2030	2032	2033	2037
4	Humber	2030	2031	2031	2031	2033	2035	2038
5	North Wales	2031	2031	2032	2032	2034	2036	2039
6	Severn Estuary (Low)	2032	2032	2033	2033	2035	2036	2040
7	Morecambe	2033	2033	2034	2034	2036	2037	2041

5.3 High Ambition

The high ambition scenario represents a very ambitious phasing of eleven tidal range generation assets, with the first asset coming online in 2032, and one being delivered every year until 2042. This scenario is intended to represent the upper envelope of ambition, with a centrally, public led programme intending to deliver as much capacity as quickly as possible. It has been assumed that only one Strategic Outline Case (SOC) would be undertaken for all the tidal range generation assets. The entire timeline is compressed, for example with the DCO process taking just 2 years. In order to realise this, there would be significant streamlining and time reduction required across leasing, licencing and construction. Significant investment in local supply chain would likely be required, and there would be overlap between the development and construction of multiple projects at a time. This includes the support suggested in 3.1.3 and proposed programme reductions in 5.4.6.

It is recognised that the high ambition scenario is a significant departure from current practices, and has mostly been included in the study as an 'upper bound' for analysis.

A draft programme is given in Appendix A.3 with key dates below:

Table 5-3: *High ambition scenario key dates*

Lagoon No.	Location	Task(s) Start Year						
		SOC	Lease agreement	Grid connection and DCO	OBC	FBC / FID	Construction	Lagoon online
1	Liverpool Bay	2026	2026	2026	2027	2027	2028	2032
2	Severn Estuary (High)	-	2027	2027	2027	2028	2029	2033
3	Solway	-	2028	2028	2028	2029	2030	2034
4	Humber	-	2028	2029	2029	2030	2031	2035

5	North Wales	-	2029	2030	2030	2031	2032	2036
6	Severn Estuary (Low)	-	2030	2031	2031	2032	2033	2037
7	Morecambe	-	2031	2031	2032	2033	2034	2038
8	Thames	-	2032	2032	2033	2034	2035	2039
9	Ribble		2033	2033	2034	2035	2036	2040
10	Wash		2034	2034	2035	2036	2037	2041
11	Rye		3035	2035	2036	2037	2037	2042

5.4 Potential for Programme and Budget Reduction

5.4.1 Strategic Assessment and Strategic Outline Case (SOC)

The strategic assessment and SOC are the first steps in developing a project proposal via the Five Case Model. A standardised lagoon design and delivery mechanisms could streamline the strategic assessment and strategic outline case stages by enabling more similarities across projects.

Should a nationalised programme be introduced, there is the potential that a single business case be carried out for a 'fleet' of assets, and therefore time and budget being saved for later assets.

5.4.2 Seabed Leasing

The Crown Estate (TCE) and the Crown Estate Scotland (CES) are the approving authorities for seabed leases in UK waters for offshore wind, wave and tidal stream projects. TCE identifies suitable areas of the seabed for project development, and developers can bid for seabed lease rights through leasing rounds. There is no confirmed or existing TCE leasing round for tidal range projects, and so a tidal range developer would need to independently consult with TCE. Opening the leasing rounds to tidal range could increase investment interest and streamline the seabed leasing process for a tidal range developer.

5.4.3 Grid Connection

To secure an onshore grid connection, a tidal range developer would need to consult with NESO, which balances the electricity network in England and Wales and manages the connection process to the National Electricity Transmission System (NETS), which is owned by national Grid Electricity Transmission (NGET). Currently, achieving a grid connection can be a significant bottleneck in the development of a project, with significant queues. In April 2025, Ofgem approved NESO's TMO4+ reform package, which aims to transition to a 'First Ready, First Needed, First Connected' model. This will prioritise projects which are ready to progress and align with strategic energy needs and could be beneficial in enabling tidal range projects to secure grid connection agreements.

5.4.4 Development Consenting Order (DCO) Process

DCO is a legal document which awards permission for the construction and operation of a Nationally Significant Infrastructure Project (NSIP). shows the criteria from the Planning Act 2008 which dictates whether a project qualifies as an NSIP.

Table 5-4: *Criteria for a project to be classed as a NSIP in England and Wales*

Part of the PA 2008	Criteria to be NSIP
15 (2)	In England; not wind generation; onshore; and more than 50 MW.
15 (3)	Offshore; more than 100 MW
15 (3B)	In waters adjacent to Wales; up to limit of the territorial sea or in the Welsh Zone; more than 350 MW.

Based on this, all proposed projects across the low, medium and high ambition scenarios (~700 MW) would be classed as NSIPs and would therefore require DCO.

The DCO process can be lengthy, with the pre-application stage taking around five years according to the BHA[23], due to the high volume of evidence required, such as surveys, environmental impact assessment (EIA) and stakeholder consultation and engagement. Following completion of the pre-application, the remainder of the process can take around 18 months[24]. As a result, DCO timelines represent a significant barrier to delivering a high ambition scenario in particular, which would need to be addressed should this scenario be identified as desirable, noting that it has been included in this exercise primarily to act as an upper bound.

In addition to this, government's NSIP Action Plan was implemented in Spring 2024, however reforms that could apply to tidal range projects are not yet in full effect, such as designating low-carbon NSIPs as 'Critical National Priorities'.

5.4.5 Full Business Case and Final Investment Decision

The Full Business Case (FBC) is the procurement phase of the project, following the Five Case Model. Should a RAB mechanism be enabled the risk of investment is greatly reduced and therefore this stage may be reduced. As discussed in earlier paragraphs, there is also potential for individual business cases not being required per asset should a nationalised roll-out plan be adopted.

5.4.6 Construction

The construction time of a tidal range lagoon would depend on many factors, including the local supply chain capability and project size, however, it is assumed that current construction time would be around five years. The number of proposed tidal range projects in the medium and high ambition scenarios would pose a strain on the relevant supply chain (particularly if being delivered concurrently with offshore wind projects). This includes materials, manufacturing facilities, offshore transport, workforce and logistics which will overlap with offshore wind projects. Whilst this also provides an opportunity for UK manufacturing capabilities, a range of construction techniques may be required to reduce supply chain pressures and accelerate delivery.

The key unique civil engineering elements of a tidal range scheme are the bund walls (used to enclose a body of water) and the powerhouse structure (used to house the turbines and associated M&E elements). Although the construction of these are well established techniques, some innovation in relation to how previous constructed and proposed tidal projects have been designed is considered.

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[23] *Tidal Range Alliance, tidal range Alliance - British Hydropower Association*

[24] *The process for Nationally Significant Infrastructure Projects, https://national-infrastructure-consenting.planninginspectorate.gov.uk/decision-making-process-guide*

Bund design

La Rance power station and the proposed Swansea Bay Tidal lagoon utilised bunds consisting largely of rock armour, with a core of ungraded fill material or dredged sand. The scale of proposed projects would require very large material volumes to construct these, with long timescales. An alternative construction method could utilise concrete caissons for bund which would largely be constructed offsite and floated into position, similar to recent UK projects such as the Aberdeen port upgrade.

The cost and time savings associated with using pre-cast concrete caissons are also increased if additional tidal range generation assets are built, reusing design and production facilities. However, careful consideration of weather windows is needed for floating out and installing the caissons, as the wave and tidal conditions of potential project locations may constrain installation timeframes.

Powerhouse design

A key innovation around the design of the powerhouse as a general principle is utilising modular and / or offsite construction techniques, noting that at specific sites more innovative methods could be possible. A standardised powerhouse design would allow the use of Design for Manufacture and Assembly (DfMA) techniques, where elements are constructed onshore and then assembled on site. This could be applied to civil concrete elements, as well as mechanical balance of plant.

Local manufacturer development

The rollout of a programme of tidal range projects could result in investment in local manufacturing capability. For example, the production of a local turbine manufacturing facility, with security that a certain number of turbines will be produced there for the duration of the programme.

Vessels

A key limitation in the construction of tidal range projects is likely to be vessel availability, particularly with competition with the development of offshore wind projects which would require the same vessels. A secured programme of tidal range projects could incentivise the purchasing of local vessels to be used in the construction of both the tidal range projects and local offshore wind projects.

6. Appendix

Appendix A – List of Acronyms

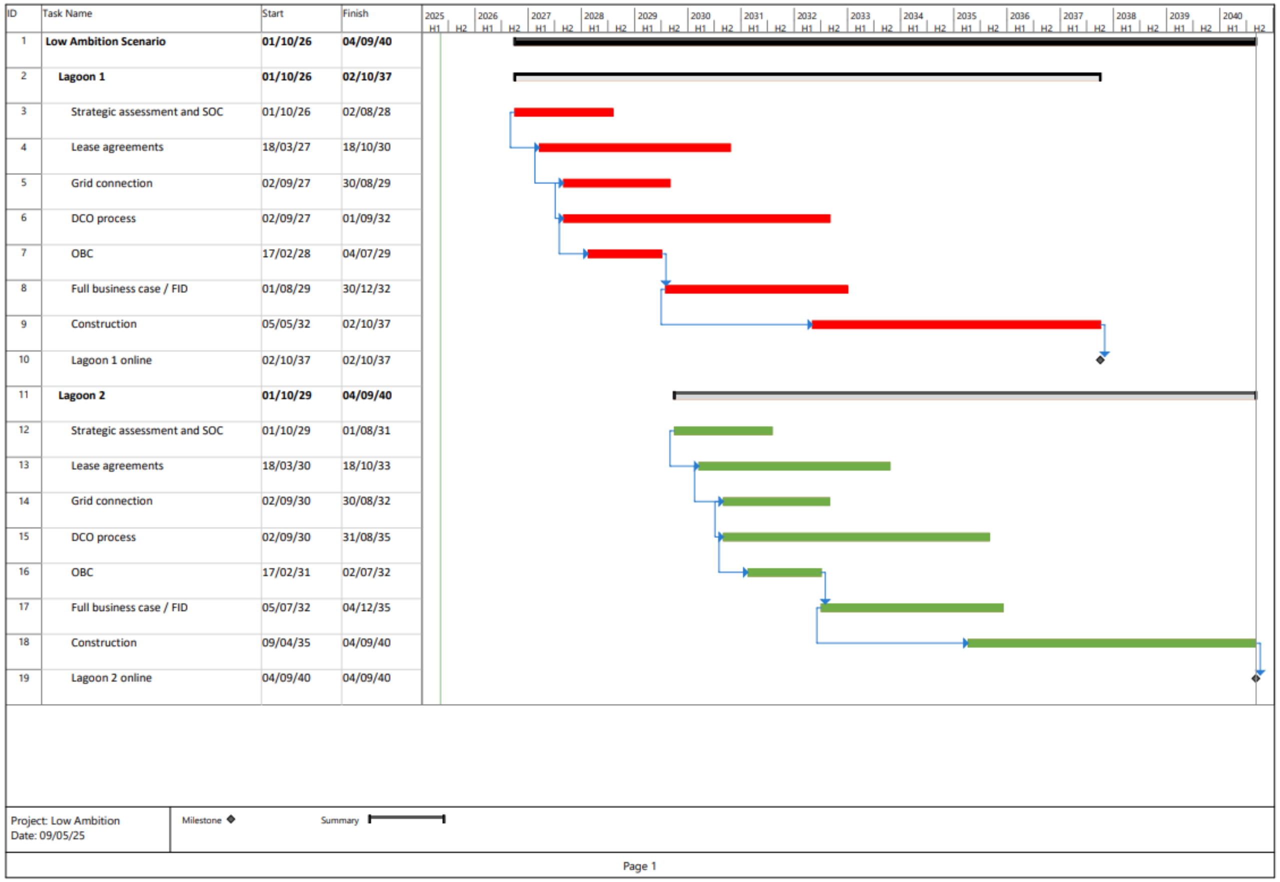
Acronym	Meaning
ATT	Arup Tidal Tool
BESS	Battery Energy Storage Systems
BHA	British Hydropower Association
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CCGT	Combined Cycle Gas Turbine
CCUS	Carbon Capture Usage and Storage
CES	Crown Estate Scotland
CfD	Contracts for Difference
DESNZ	Department for Energy Security and Net Zero
DEVEX	Development Expenditure
DCO	Development Consent Order
EC5	East Coast Boundary 5
ESOET	Electricity System Operator Executive Team

Acronym	Meaning
ESOC	Electricity System Operator Committee
ETYS	Electricity Ten Year Statement
FBC	Full Business Case
FES	Future Energy Scenarios
FID	Final Investment Decision
GB	Great Britain
GVA.s	Gigavolt-amperes-seconds
HE	Hydrogen Evolution
LCOE	Levelised Cost of Energy
NESO	National Energy System Operator
NOA	Network Options Assessment
NW2	North West Boundary 2
NPV	Net Present Value
O&M	Operations & Maintenance
RAB	Regulated Asset Base
REPEX	Replacement Expenditure

Acronym	Meaning
SC1	Scottish Boundary 1
SCL	Short Circuit Level
SW1	South West Boundary 1
TLSB	Tidal Lagoon Swansea Bay
TCE	The Crown Estate
WACC	Weighted Average Cost of Capital

Appendix B - Rollout Programmes

Appendix B.1 – Low Ambition Scenario



ID	Task Name	Start	Finish
1	**Low Ambition Scenario**	**01/10/26**	**04/09/40**
2	**Lagoon 1**	**01/10/26**	**02/10/37**
3	Strategic assessment and SOC	01/10/26	02/08/28
4	Lease agreements	18/03/27	18/10/30
5	Grid connection	02/09/27	30/08/29
6	DCO process	02/09/27	01/09/32
7	OBC	17/02/28	04/07/29
8	Full business case / FID	01/08/29	30/12/32
9	Construction	05/05/32	02/10/37
10	Lagoon 1 online	02/10/37	02/10/37
11	**Lagoon 2**	**01/10/29**	**04/09/40**
12	Strategic assessment and SOC	01/10/29	01/08/31
13	Lease agreements	18/03/30	18/10/33
14	Grid connection	02/09/30	30/08/32
15	DCO process	02/09/30	31/08/35
16	OBC	17/02/31	02/07/32
17	Full business case / FID	05/07/32	04/12/35
18	Construction	09/04/35	04/09/40
19	Lagoon 2 online	04/09/40	04/09/40

Project: Low Ambition
Date: 09/05/25

Milestone ◆

Summary

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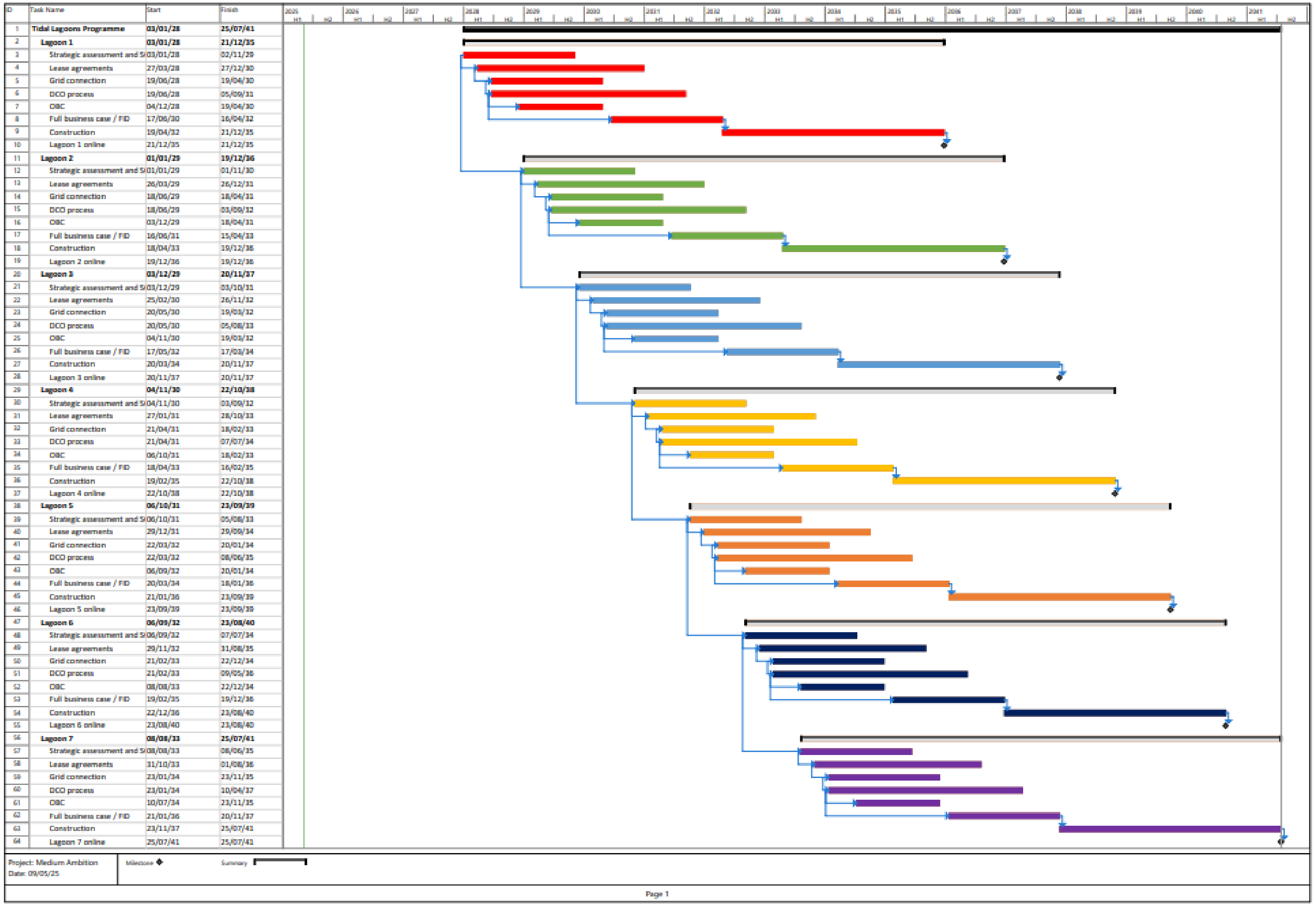
Appendix B.2 – Medium Ambition Scenario



ID	Task Name	Start	Finish
1	**Tidal Lagoons Programme**	**03/01/28**	**25/07/41**
2	**Lagoon 1**	**03/01/28**	**21/12/35**
3	Strategic assessment and S	03/01/28	02/11/29
4	Lease agreements	27/03/28	27/12/30
5	Grid connection	19/06/28	19/04/30
6	DCO process	19/06/28	05/09/31
7	OBC	04/12/28	19/04/30
8	Full business case / FID	17/06/30	16/04/32
9	Construction	19/04/32	21/12/35
10	Lagoon 1 online	21/12/35	21/12/35
11	**Lagoon 2**	**01/01/29**	**19/12/36**
12	Strategic assessment and S	01/01/29	01/11/30
13	Lease agreements	26/03/29	26/12/31
14	Grid connection	18/06/29	18/04/31
15	DCO process	18/06/29	03/09/32
16	OBC	03/12/29	18/04/31
17	Full business case / FID	16/06/31	15/04/33
18	Construction	18/04/33	19/12/36
19	Lagoon 2 online	19/12/36	19/12/36
20	**Lagoon 3**	**03/12/29**	**20/11/37**
21	Strategic assessment and S	03/12/29	03/10/31
22	Lease agreements	25/02/30	26/11/32
23	Grid connection	20/05/30	19/03/32
24	DCO process	20/05/30	05/08/33
25	OBC	04/11/30	19/03/32
26	Full business case / FID	17/05/32	17/03/34
27	Construction	20/03/34	20/11/37
28	Lagoon 3 online	20/11/37	20/11/37
29	**Lagoon 4**	**04/11/30**	**22/10/38**
30	Strategic assessment and S	04/11/30	03/09/32
31	Lease agreements	27/01/31	28/10/33
32	Grid connection	21/04/31	18/02/33
33	DCO process	21/04/31	07/07/34
34	OBC	06/10/31	18/02/33
35	Full business case / FID	18/04/33	16/02/35
36	Construction	19/02/35	22/10/38
37	Lagoon 4 online	22/10/38	22/10/38
38	**Lagoon 5**	**06/10/31**	**23/09/39**
39	Strategic assessment and S	06/10/31	05/08/33
40	Lease agreements	29/12/31	29/09/34
41	Grid connection	22/03/32	20/01/34
42	DCO process	22/03/32	08/06/35
43	OBC	06/09/32	20/01/34
44	Full business case / FID	20/03/34	18/01/36
45	Construction	21/01/36	23/09/39
46	Lagoon 5 online	23/09/39	23/09/39
47	**Lagoon 6**	**06/09/32**	**23/08/40**
48	Strategic assessment and S	06/09/32	07/07/34
49	Lease agreements	29/11/32	31/08/35
50	Grid connection	21/02/33	22/12/34
51	DCO process	21/02/33	09/05/36
52	OBC	08/08/33	22/12/34
53	Full business case / FID	19/02/35	19/12/36
54	Construction	22/12/36	23/08/40
55	Lagoon 6 online	23/08/40	23/08/40
56	**Lagoon 7**	**08/08/33**	**25/07/41**
57	Strategic assessment and S	08/08/33	08/06/35
58	Lease agreements	31/10/33	01/08/36
59	Grid connection	23/01/34	23/11/35
60	DCO process	23/01/34	10/04/37
61	OBC	10/07/34	23/11/35
62	Full business case / FID	21/01/36	20/11/37
63	Construction	23/11/37	25/07/41
64	Lagoon 7 online	25/07/41	25/07/41

Project: Medium Ambition
Date: 09/05/25

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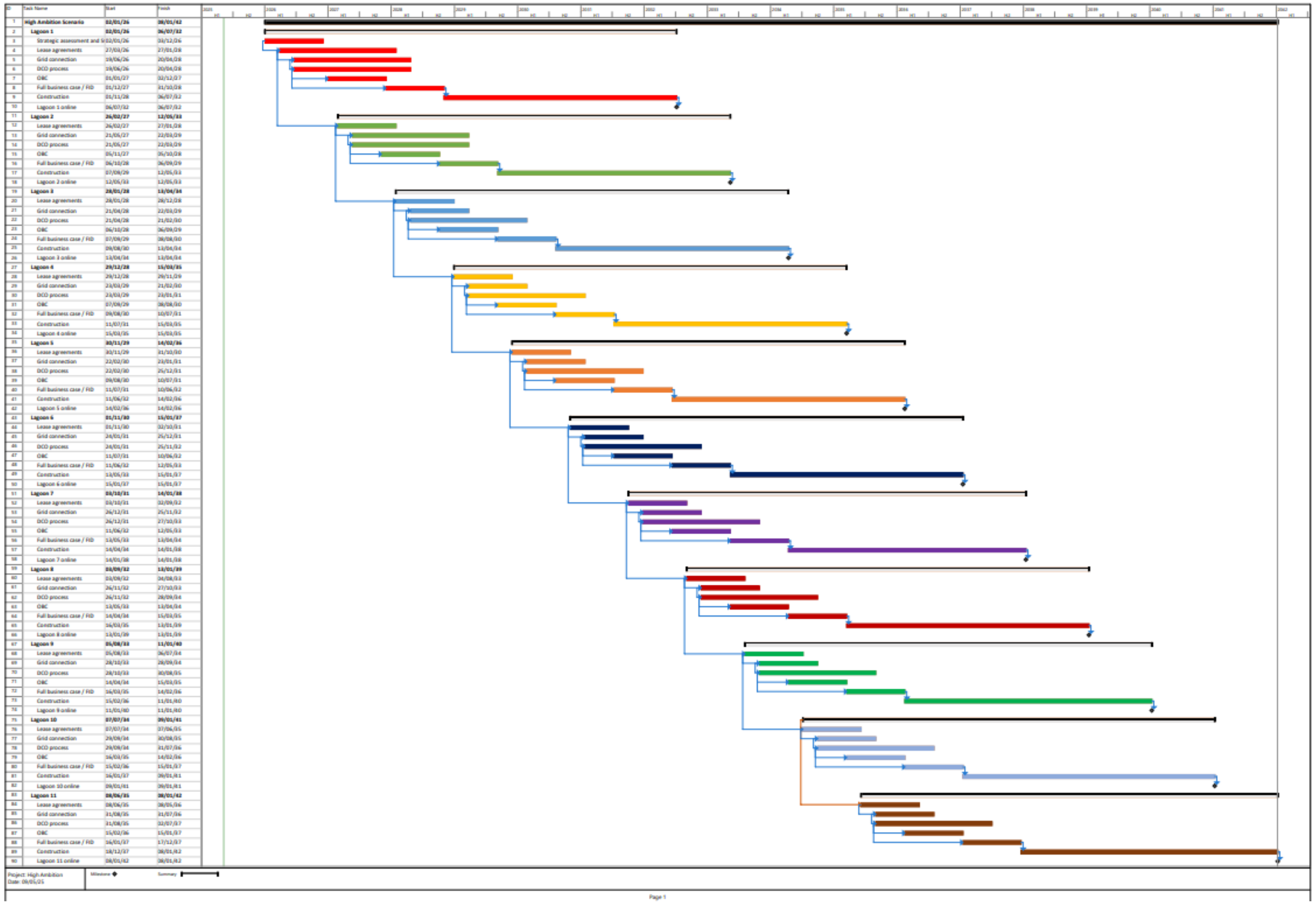
Appendix B.3 – High Ambition Scenario



ID	Task Name	Start	Finish
1	**High Ambition Scenario**	**02/01/26**	**08/01/42**
2	**Lagoon 1**	**02/01/26**	**06/07/32**
3	Strategic assessment and S	02/01/26	03/12/26
4	Lease agreements	27/03/26	27/01/28
5	Grid connection	19/06/26	20/04/28
6	DCO process	19/06/26	20/04/28
7	OBC	01/01/27	02/12/27
8	Full business case / FID	01/12/27	31/10/28
9	Construction	01/11/28	06/07/32
10	Lagoon 1 online	06/07/32	06/07/32
11	**Lagoon 2**	**26/02/27**	**12/05/33**
12	Lease agreements	26/02/27	27/01/28
13	Grid connection	21/05/27	22/03/29
14	DCO process	21/05/27	22/03/29
15	OBC	05/11/27	05/10/28
16	Full business case / FID	06/10/28	06/09/29
17	Construction	07/09/29	12/05/33
18	Lagoon 2 online	12/05/33	12/05/33
19	**Lagoon 3**	**28/01/28**	**13/04/34**
20	Lease agreements	28/01/28	28/12/28
21	Grid connection	21/04/28	22/03/29
22	DCO process	21/04/28	21/02/30
23	OBC	06/10/28	06/09/29
24	Full business case / FID	07/09/29	08/08/30
25	Construction	09/08/30	13/04/34
26	Lagoon 3 online	13/04/34	13/04/34
27	**Lagoon 4**	**29/12/28**	**15/03/35**
28	Lease agreements	29/12/28	29/11/29
29	Grid connection	23/03/29	21/02/30
30	DCO process	23/03/29	23/01/31
31	OBC	07/09/29	08/08/30
32	Full business case / FID	09/08/30	10/07/31
33	Construction	11/07/31	15/03/35
34	Lagoon 4 online	15/03/35	15/03/35
35	**Lagoon 5**	**30/11/29**	**14/02/36**
36	Lease agreements	30/11/29	31/10/30
37	Grid connection	22/02/30	23/01/31
38	DCO process	22/02/30	25/12/31
39	OBC	09/08/30	10/07/31
40	Full business case / FID	11/07/31	10/06/32
41	Construction	11/06/32	14/02/36
42	Lagoon 5 online	14/02/36	14/02/36
43	**Lagoon 6**	**01/11/30**	**15/01/37**
44	Lease agreements	01/11/30	02/10/31
45	Grid connection	24/01/31	25/12/31
46	DCO process	24/01/31	25/11/32
47	OBC	11/07/31	10/06/32
48	Full business case / FID	11/06/32	12/05/33
49	Construction	13/05/33	15/01/37
50	Lagoon 6 online	15/01/37	15/01/37
51	**Lagoon 7**	**03/10/31**	**14/01/38**
52	Lease agreements	03/10/31	02/09/32
53	Grid connection	26/12/31	25/11/32
54	DCO process	26/12/31	27/10/33
55	OBC	11/06/32	12/05/33
56	Full business case / FID	13/05/33	13/04/34
57	Construction	14/04/34	14/01/38
58	Lagoon 7 online	14/01/38	14/01/38
59	**Lagoon 8**	**03/09/32**	**13/01/39**
60	Lease agreements	03/09/32	04/08/33
61	Grid connection	26/11/32	27/10/33
62	DCO process	26/11/32	28/09/34
63	OBC	13/05/33	13/04/34
64	Full business case / FID	14/04/34	15/03/35
65	Construction	16/03/35	13/01/39
66	Lagoon 8 online	13/01/39	13/01/39
67	**Lagoon 9**	**05/08/33**	**11/01/40**
68	Lease agreements	05/08/33	06/07/34
69	Grid connection	28/10/33	28/09/34
70	DCO process	28/10/33	30/08/35
71	OBC	14/04/34	15/03/35
72	Full business case / FID	16/03/35	14/02/36
73	Construction	15/02/36	11/01/40
74	Lagoon 9 online	11/01/40	11/01/40
75	**Lagoon 10**	**07/07/34**	**09/01/41**
76	Lease agreements	07/07/34	07/06/35
77	Grid connection	29/09/34	30/08/35
78	DCO process	29/09/34	31/07/36
79	OBC	16/03/35	14/02/36
80	Full business case / FID	15/02/36	15/01/37
81	Construction	16/01/37	09/01/41
82	Lagoon 10 online	09/01/41	09/01/41
83	**Lagoon 11**	**08/06/35**	**08/01/42**
84	Lease agreements	08/06/35	08/05/36
85	Grid connection	31/08/35	31/07/36
86	DCO process	31/08/35	02/07/37
87	OBC	15/02/36	15/01/37
88	Full business case / FID	16/01/37	17/12/37
89	Construction	18/12/37	08/01/42
90	Lagoon 11 online	08/01/42	08/01/42

Project: High Ambition
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