FLOMax: Flexible Operation for Maximal Value Summary Report

As part of the Tidal Lagoon Challenge

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Date: 17th March 2026

In partnership with:

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DOCUMENT HISTORY

Revision	Date	Prepared by	Checked by	Approved by	Revision History
Rev 1	17.03.26	RJ	DL, KD	MK	Rev001
Draft 1					
Draft 2					

Field	Detail
Report Title	FLOMax: Flexible Operation for Maximal Value Final Report
Status	Public
Document Reference	PN000715-RPT-004

PREFACE

ORE Catapult, Intertek Metoc and Cardiff University have been commissioned on one of the Welsh Government's Tidal Lagoon Challenge (TLC) research projects to assess the long-term value of tidal lagoon projects. This project investigates the impact of flexible lagoon operation alongside various future energy scenarios, to better quantify the value of tidal range energy to the UK energy system, titled Flexible Lagoon Operation for Maximal Value (FLOMax).

Each distinct Work Package has a separate report with detailed methodology. This Summary Report aims to pull out key findings.

CONTENTS

1 EXECUTIVE SUMMARY

This report presents the findings of the Flexible Operation for Maximal Value (FLOMax) project, commissioned as part of the Welsh Government's Tidal Lagoon Challenge (TLC) research programme. The project investigates how tidal lagoon systems could contribute to the future UK energy system by evaluating the effects of flexible operational strategies, future electricity market conditions, and long-term climate change scenarios on the performance and value of tidal range energy.

A modelling framework was developed to assess both the technical performance and economic value of tidal lagoons. Hydrodynamic modelling was used to estimate electricity generation under a range of design configurations and operational strategies. The analysis shows that flexible lagoon operation can significantly improve electricity generation of up to 18% without requiring additional infrastructure. These improvements arise from the ability to adjust turbine operation, sluicing, and pumping in response to tidal conditions and electricity market signals.

Electricity market modelling indicates that tidal lagoons could provide reliable and predictable income in future power systems. Looking ahead to 2035, the results vary depending on how stable or volatile the electricity market is. In stable ("calm") market conditions, tidal lagoons are projected to generate annual revenues of around £502 million to £636 million. In contrast, in more volatile markets—where electricity prices spike more often due to supply shortages—revenues could increase significantly to about £1.1–£1.16 billion per year. This is because tidal lagoons can generate power at predictable times, allowing them to benefit when prices are higher.

Importantly, tidal lagoons show very low cannibalisation effects. This means that, unlike some other renewable technologies (such as wind or solar), they do not significantly drive down the market price when they generate electricity. In practice, their capture price is usually within 5% of the overall market price, indicating they integrate well into the system without distorting prices. As a result, adding tidal lagoons to the energy mix is unlikely to increase costs for consumers through price suppression effects. At the same time, they can contribute to energy security (by providing predictable, domestic power) and support economic growth, particularly through supply chain development and infrastructure investment. Tidal lagoon generation can reduce extreme electricity price events, with scarcity price peaks above £300/MWh reduced by up to 48.7% in some scenarios. The presence of lagoons also contributes to electricity price volatility reductions of up to 10.9%, particularly in systems with high renewable penetration.

Financial modelling highlights the importance of appropriate financing structures for large-scale tidal range infrastructure. The analysis indicates that a Regulated Asset Base (RAB) financing model could significantly reduce the cost of capital, distribute costs more evenly across the asset's long operational life, and provide stronger incentives for efficient project delivery while protecting consumers. LCOE projections improved by 30% using an RAB mechanism for a 2000 MW lagoon in the Severn Estuary.

Overall, the findings suggest that tidal lagoons could play a valuable role in the UK's future low-carbon electricity system by providing predictable renewable generation, improving system resilience, and supporting long-term industrial development. Analysis demonstrated opportunities for regional economic activity, and when delivered alongside other renewable energy projects, there are clear synergies in both manufacturing capability and quayside infrastructure. Further work is recommended to continue advancing operational optimisation, turbine technology, and financing models to enable the commercial deployment of tidal range projects.

2 INTRODUCTION

The United Kingdom has committed to achieving net-zero greenhouse gas emissions by 2050, requiring a fundamental transformation of the energy system. This transition will rely heavily on the large-scale deployment of renewable energy sources such as wind and solar. However, these technologies are inherently variable and weather-dependent, creating challenges for maintaining electricity system stability and ensuring reliable supply. Tidal energy remains a significantly underutilised renewable energy resource despite the UK possessing up to half of Europe's exploitable tidal resources. Wales, with its abundant tidal range potential and existing industrial capabilities, is uniquely positioned to spearhead the development of tidal lagoon power stations. Optimisation of tidal range schemes has primarily focused on maximising electricity output by optimising operational schemes and design parameters, thereby reducing the cost per unit of electricity generated. However, there is a need to evaluate the long-term operational benefits of flexible schemes and the comparative analysis of designs in Wales since the economic design of tidal range schemes are long-term endeavour that must also account for climate change impacts during both construction and subsequent operation.

Tidal range energy represents a potentially valuable complement to other renewable technologies. Unlike wind and solar generation, tidal cycles are highly predictable decades in advance, allowing tidal power to provide reliable and forecastable electricity generation. Tidal lagoons in particular offer the ability to generate power during both the flood and ebb phases of the tide and, when combined with pumping capabilities, can operate flexibly to optimise energy production and respond to electricity market conditions.

Despite this potential, the large-scale deployment of tidal lagoons remains limited. Key barriers include the high upfront capital cost, long construction timelines, and uncertainty regarding the value that tidal generation can deliver within a future energy system dominated by renewables. Understanding the long-term technical and economic value of tidal lagoons is therefore critical for informing energy policy and investment decisions. The Flexible Operation for Maximal Value (FLOMax) project was undertaken to address these challenges. Commissioned as part of the Welsh Government's Tidal Lagoon Challenge, the project investigates how tidal lagoon infrastructure could be designed and operated to maximise its contribution to the UK energy system over the coming decades.

To assess the potential value of tidal lagoons, the project integrates several complementary modelling approaches. Hydrodynamic models are used to simulate tidal flows and estimate electricity generation under different operational strategies and future sea-level scenarios. These results are then combined with electricity market modelling that simulates wholesale price formation in future decarbonised energy systems. The modelling framework also considers multiple energy transition pathways and incorporates stochastic simulations to represent uncertainty in future market conditions.

In addition to technical and market analysis, the project examines the financial structures required to support large-scale tidal lagoon development, including alternative infrastructure financing models. The study also considers broader innovation opportunities and potential benefits for the UK supply chain and regional industrial development. By combining engineering, energy system modelling, and financial analysis, this report aims to provide a comprehensive assessment of how flexible tidal lagoon operation could maximise the value of tidal range energy within the future UK electricity system.

3 SITE SELECTION

Case study locations were selected based on several technical and strategic considerations to ensure that the modelling results are representative of future large-scale tidal range development. Full methodology is available in report *WP1: Identify and define the most beneficial parameters for further investigation.*

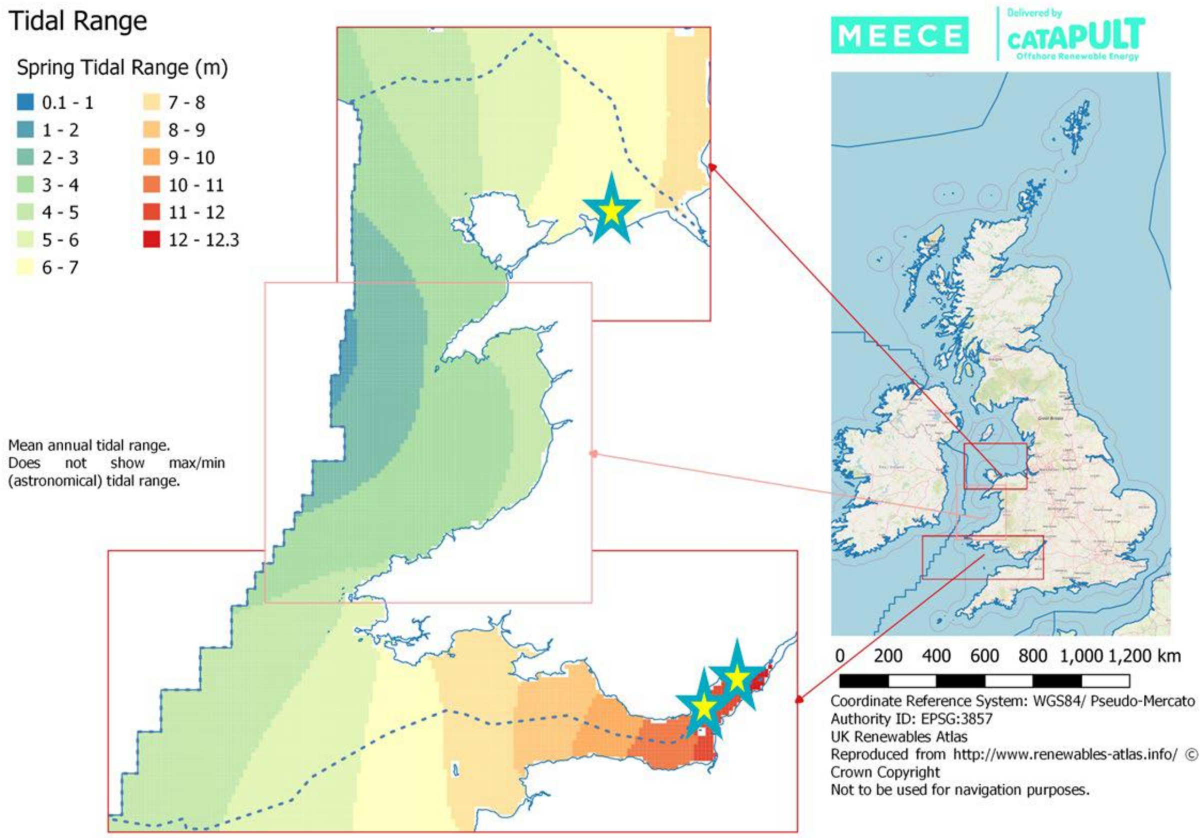
To align with future commercial deployment and provide meaningful impacts on power systems, only schemes with an installed capacity greater than 1 GW are considered. This ensures the modelling reflects installations capable of contributing significantly to energy supply and grid stability. Met Office sea-level rise projections up to the year 2300 were adopted [1], based upon climate scenario RPC4.5, as outlined in the IPCC AR5 report [2]. Given that the design life of these projects is expected to be at least 125 years with adequate servicing and maintenance, climate change scenarios must be incorporated into the analysis. Therefore, sea level rise in the estimated construction year of 2035 will serve as the baseline scenario, with additional climate projections considered for the years 2050, 2085, and 2135.

3.1 Selected Case Study Sites

Based on the above criteria and the availability of existing design data, three previously proposed tidal lagoon schemes are selected for detailed modelling:

- **North Wales Tidal Lagoon** (NWTL) is proposed by North Wales Tidal Energy to be built on the North Wales coast from Llandudno to Prestatyn [3], as shown in Figure 1-2. It would comprise a 31 km long impoundment wall enclosing an area of 157 km2. Based on the initial assessment, the scheme would use 150 no. 20 MW bi-directional turbines with a diameter of 7m.
- **Cardiff Tidal Lagoon** (CTL) is a proposed large-scale tidal energy project located in the Severn Estuary, between Cardiff and Newport, South Wales. The lagoon would be situated approximately 2 km from the entrance to Cardiff Bay on its western extent and 2 km from the mouth of the River Usk on its eastern edge, extending up to 8 km offshore into the estuary. The proposed structure would form a 14-mile (22.5 km) breakwater, enclosing a tidal area of approximately 70 km^2.
- **Newport Tidal Lagoon** (NTL) is a proposed tidal energy project situated to the immediate east of the River Usk, enclosing a portion of the estuary between Newport and the eastern edge of Cardiff. While the precise design parameters are still under development, the lagoon is expected to follow a similar engineering concept to its sister projects: a breakwater structure enclosing a tidal basin, equipped with low-head hydro turbines capable of generating electricity on both the flood and ebb tides.

These sites provide representative examples of tidal lagoon development in regions with significant tidal resources. Including sites in both North and South Wales also allows the study to examine regional interactions and the potential for phased generation across different tidal regimes to improve grid balancing. The schemes have been previously investigated, meaning sufficient design and environmental data are available to support modelling without requiring the development of entirely new conceptual designs.



Mean annual tidal range. Does not show max/min (astronomical) tidal range.

Coordinate Reference System: WGS84/ Pseudo-Mercato
Authority ID: EPSG:3857
UK Renewables Atlas
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Figure 1. Locations of Tidal Lagoon Projects Being Investigated: North Wales Tidal Lagoon, Cardiff Tidal Lagoon, and Newport Tidal Lagoon

3.2 Key Design and Operational Assumptions

Tidal lagoons are assumed to utilise Kaplan bulb turbines, which are widely used in low-head tidal applications due to their high efficiency and ability to operate under varying hydraulic conditions. The baseline operational configuration assumes two-way generation (ebb and flood) combined with pumping capability. Pumping allows operators to maintain pre-construction tidal levels within the lagoon, potentially reducing environmental impacts and increasing operational flexibility.

4 MODELLING METHODOLOGY

Energy output modelling was undertaken to estimate the potential electricity generation from the proposed tidal lagoon schemes and evaluate their technical feasibility. The modelling enables assessment of how different design configurations and operational strategies influence power production, helping to identify optimal turbine arrangements, operating parameters, and lagoon layouts. The modelling provides insight into how tidal lagoons could contribute to future energy supply, grid stability, and renewable energy integration, particularly by providing predictable power that complements intermittent sources such as wind and solar. The results also form a basis for subsequent economic, environmental, and system-level analyses within the wider project. Full methodology and analysis are available in report *WP2: Tidal Range Modelling* and is briefly described here.

4.1 Hydrodynamic Modelling

Energy output modelling was undertaken to estimate potential electricity generation from proposed tidal lagoon schemes and assess how design and operational strategies influence performance. The modelling framework combines zero-dimensional (0-D) and two-dimensional (2-D) hydrodynamic models.

4.1.1 Zero-dimensional (0-D) Hydrodynamic Modelling

A 0-D hydrodynamic model was used to estimate water levels and energy generation within tidal lagoons. Water levels for energy generation prediction were calculated using the mass conservation (continuity) equation, which assumes that the change in water level within a lagoon is determined by the balance between inflowing and outflowing discharge. In the 0-D modelling approach, hydrodynamic effects are simplified by assuming that water within the impoundment is distributed uniformly and instantaneously, allowing lagoon water levels to be calculated from previous upstream levels, downstream conditions, and turbine or sluice discharges.

Turbine discharge and power output were estimated using performance data for Andritz Hydro bulb turbines and Tidetec turbines, with an efficiency reduction applied for reverse operation of the Andritz turbines. The 0-D model provides a computationally efficient method for assessing operational strategies and maximising energy generation during early-stage feasibility studies, although it may overestimate generation by approximately 10–40% compared to higher-dimensional hydrodynamic models.

4.1.2 Two-dimensional (2-D) Hydrodynamic Modelling

To provide a more realistic representation of tidal dynamics, a 2-D hydrodynamic model was developed using Delft3D Flexible Mesh of the South Wales and Severn Estuary, to simulate tidal flows and estimate energy generation for the Cardiff and Newport tidal lagoons. Unlike the simplified 0-D model, the 2-D model accounts for spatial variations in water levels, flow velocities, bathymetry, and hydrodynamic interactions between lagoons, providing a more realistic representation of tidal dynamics.

The model domain extends from Milford Haven to the River Severn, incorporating detailed bathymetry derived from survey data, nautical charts, and LiDAR. Lagoon structures were represented using thin dams and multiple source–sink points to simulate turbine and sluice discharges, enabling a more representative simulation of lagoon filling and emptying cycles.

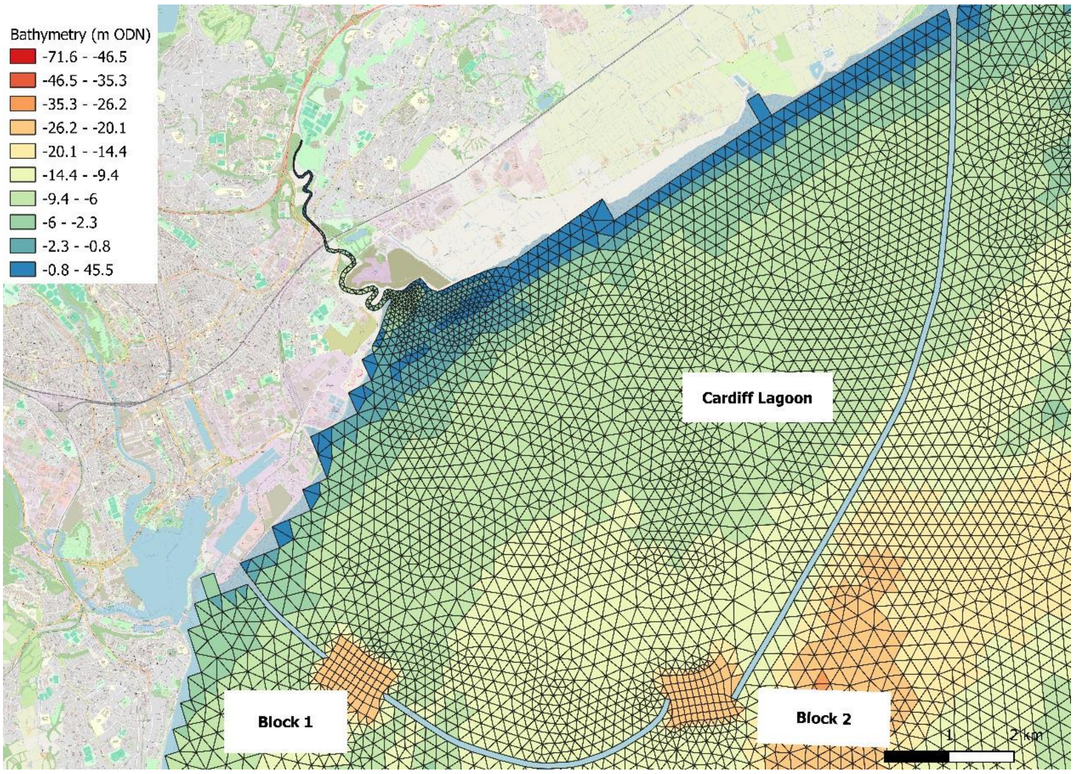


Figure 2. Computational Mesh and Model Bathymetry at Cardiff Lagoon

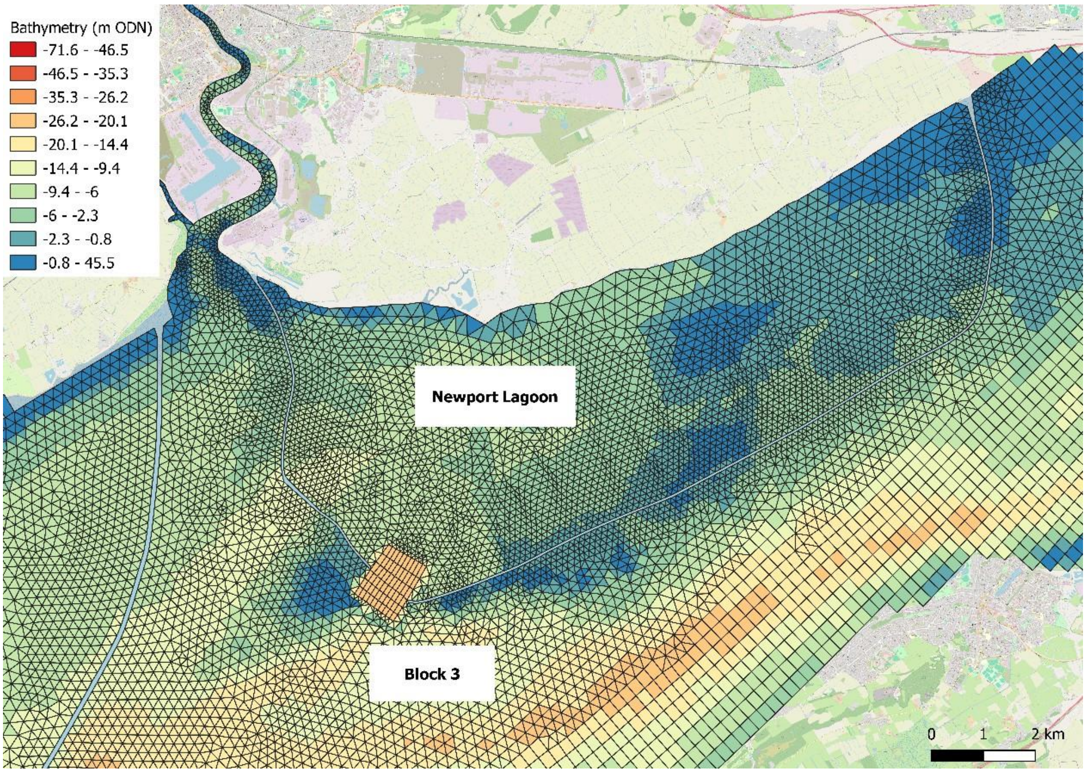


Figure 3. Computational Mesh and Model Bathymetry at Newport Lagoon

By comparing the results of the 0-D and 2-D models, the study evaluates the accuracy of simplified optimisation approaches and assesses hydrodynamic interactions between lagoons. This dual-modelling framework improves confidence in predicted energy generation and supports more robust decision-making for tidal lagoon design and operation under both present and future sea-level conditions. In terms of the time series comparison of water levels between 0-D and 2-D, it shows good agreement for the CTL and NTL for all simulation years of 2035, 2050, 2085, and 2135, indicating that the discharge distribution and operational assumptions are well represented in both models.

4.2 Electricity Price and Market Modelling

The electricity market model was developed to evaluate the financial performance and system-wide impacts of tidal lagoon generation in a future decarbonised GB electricity system. The framework integrates a fundamental merit-order dispatch model with statistical market modelling and stochastic price dynamics to reproduce realistic wholesale electricity price behaviour.

Within the electricity market model historical data was used to set market behaviour parameters. These parameters were taken from 2019 data to simulate calm market dynamics and from 2021 to simulate volatile market dynamics under extreme commodity price variability and significant wind draughts. Synthetic demand and renewable generation time series are generated to represent future system conditions. Monte Carlo simulation is used to evaluate tidal lagoon revenues under multiple stochastic market scenarios. Full methodological details are provided in WP3 – Quantifying the Value of Tidal Lagoons.

4.2.1 Demand and Renewable Supply Forecasting

Future electricity demand was derived using the National Energy System Operator (NESO) Future Energy Scenarios (FES) framework. [4] These scenarios represent alternative pathways to achieving UK net-zero targets by 2050 and include differing levels of electrification, hydrogen adoption, and technology deployment. The framework outlines four scenario pathways of realistic future energy mixes - Holistic Transition, Electric Engagement, Hydrogen Evolution and Falling Behind (counterfactual).

Because historical data cannot adequately represent future climate variability or demand behaviour, synthetic time series for electricity demand, wind generation, and solar generation were generated. A Hybrid Non-Gaussian Phase Randomised Fourier Transform (NGPRFT) method was used to generate these synthetic time series. The method preserves key statistical properties of historical data including seasonal demand patterns, daily cycles, correlations between demand and weather and extreme weather events.

The generated series were then scaled to match the installed capacity and demand levels projected in each FES scenario, producing realistic future system conditions for market simulations – note that scaling for demand was undertaken to preserve peak demand during both winter and summer months, again in line with the FES2024. Based on data availability, key modelling years were allocated to be 2035 (the target for decarbonised electricity) and 2050 (the target for economy wide net zero).

4.2.2 Merit Order Modelling

The generation mix for the Merit Order model was constructed based on projected capacities from the FES datasets from a broad range of national generation sources, interconnectors, response resources and battery storage. Each generation technology was assigned an installed capacity and where appropriate thermal efficiency, availability, fuel, carbon and operating costs. These parameters were used to compute the short-run marginal cost (SRMC) of each generator, which determines its position in the merit order dispatch stack. The market model also explicitly represents several additional system features. Interconnector imports are modelled through asymmetric pricing tranches reflecting European market clearing behaviour. Demand-side response is represented as a virtual generator within the merit order stack, allowing endogenous demand elasticity. Finally, scarcity pricing behaviour is captured through a convex markup function applied to the final generation tranches, enabling the model to reproduce extreme price formation during tight system margins. For future scenarios (2035 and 2050), parameters were derived from engineering and techno-economic projections from NESO [4] and Department for Energy Security and Net Zero (DESNZ) [5] rather than historical calibration. This avoids unrealistic extrapolation of current technologies to future systems dominated by hydrogen generation, CCS plants, and large renewable fleets. Table 1 and Table 2 show the final stacks parameters developed for the 2035 and 2050 scenarios. The day-ahead wholesale electricity market was simulated using a marginal-cost merit order dispatch model. For each half-hour settlement period:

1. Net demand is calculated by subtracting renewable generation and storage dispatch from total demand.
2. Generation units are sorted by marginal cost.
3. Generators are dispatched sequentially until net demand is met.
4. The marginal generator determines the market clearing price.

If demand exceeds available capacity, prices rise to a predefined Value of Lost Load (VOLL) ceiling representing extreme scarcity.

Table 1: Showing the main parameters used to define the 2035 merit order model used in future day-ahead market scenario creation.

Parameter/technology (Projected 2035)	**Holistic Transition**	**Electrical Engagement**	**Hydrogen Evolution**	**Falling Behind**
Economic Assumptions				
LCOH Cost Trajectory[b]	Central	High	Low	High
Gas Price Trajectory[a]	Low	Low	Low	Low
Flexibility and Storage Capacity (GW)				
Battery Storage	28.9	26.3	24.0	22.2
Demand Side Response (DSR)	4.7	5.1	2.6	2.1
Renewable Generation Capacity (GW)				
Wind (Onshore & Offshore)	120.2	107.6	99.0	83.0
Solar PV	69.2	48.7	42.0	29.9
Thermal Generation Capacity (GW)				
Unabated Natural Gas	5.4	18.4	21.8	35
Gas CCS	3.3	8.1	1.7	1.8
H2	3.9	6.1	17.7	0.0
Biomass	2.6	2.6	2.0	0.2
Baseload (GW)				

Nuclear	5.0	6.0	4.6	4.6
Inter-connectors	23.7	19.0	16.5	14.3
Tidal Lagoon Capacity[c]	4.8	4.8	4.8	4.8

Note: Capacity values represent 2035 projections extracted from the NESO FES 2024 workbook.

[a]Green Hydrogen operational assumptions (50% Capacity Factor, £40/MWh Input Price) remain constant across all Net Zero compliant scenarios with a sensitivity analysis outlined in WP3 – *Quantifying the Value of Tidal Lagoons*. **H2 fuel costs are based on NESO LCOH tool and are set by the annual production weighted average of blue and green hydrogen, as projected in the FES 2024 Workbook.**

[b]Gas Price assumptions follow the FES low trajectory for the main analysis, again with a sensitivity analysis presented in WP3 – *Quantifying the Value of Tidal Lagoons*. **Temporal changes in gas prices follow historic profiles, either 2019 for calm conditions or 2021 for volatile conditions – profiles are scaled to give average cost of fuel parity with the FES low fuel scenario.**

[c]Tidal resources was removed from the wind resource such that the total installed capacity of renewable energy remained consistent. This was done across all FES scenarios – *the WP3 – Quantifying the Value of Tidal Lagoons* also looks at the effect of scale key parameters. -

Table 2: Showing the main parameters used to define the 2050 merit order model used in future day-ahead market scenario creation.

Parameter/technology (Projected 2050)	Holistic Transition	Electrical Engagement	Hydrogen Evolution	Falling Behind
Economic Assumptions				
LCOH Cost Trajectory[b]	Central	High	Low	High
Gas Price Trajectory[a]	Low	Low	Low	Low
Flexibility and demon (GW)				
Battery Storage	35.6	31.8	29.0	23.20
Demand Side Response (DSR)	10.0	9.5	3.5	2.7
Renewable Generation Capacity (GW)				
Wind (Onshore & Offshore)	142.8	138.1	1275	107.2
Solar PV	107.9	87.2	71.7	45.2
Thermal Generation Capacity (GW)				
Unabated Natural Gas	0.0	0.0	1.0	33.8
Gas CCS	9.7	16.0	11.1	16.9
H2	19.4	21.0	44.5	5.5
Biomass	3.6	4.8	4.6	4.7
Baseload (GW)				
Nuclear	14.0	22.2	11.0	13.5
Inter-connectors	25.0	22.0	16.5	15.8
Tidal Lagoon Capacity[c]	4.8	4.8	4.8	4.8

Note: Capacity values represent 2035 projections extracted from the NESO FES 2024 workbook.

[a]Green Hydrogen operational assumptions (50% Capacity Factor, £40/MWh Input Price) remain constant across all Net Zero compliant scenarios with a sensitivity analysis outlined in WP3 – *Quantifying the Value of Tidal Lagoons*. H2 fuel costs are based on

NESO LCOH tool and are set by the annual production weighted average of blue and green hydrogen, as projected in the FES 2024 Workbook.
[b] **Gas Price assumptions follow the FES low trajectory for the main analysis, again with a sensitivity analysis presented in WP3 – *Quantifying the Value of Tidal Lagoons*. Temporal changes in gas prices follow historic profiles, either 2019 for calm conditions or 2021 for volatile conditions – profiles are scaled to give average cost of fuel parity with the FES low fuel scenario.**
[c] **Tidal resources was removed from the wind resource such that the total installed capacity of renewable energy remained consistent. This was done across all FES scenarios – *the WP3 – Quantifying the Value of Tidal Lagoons* also looks at the effect of scale key parameters.**

4.2.3 Statistical Modelling

While the Merit Order (MO) model successfully maps marginal-cost based price bounds associated with structurally balancing supply and demand, wholesale electricity prices are frequently driven by algorithmic trading behaviours, charging of risk premiums, and bidding inefficiencies. To capture this market sentiment, a statistical Linear Model (LM) was developed. The statistical model was a linear model comprising of a weighted sum of historical demand data from NESO, supply data from Balancing Mechanism Reporting Service (BMRS), day ahead market data from EPEX and temporal indicators i.e. settlement period number. A Least Absolute Shrinkage and Selection Operator (Lasso) regression was selected to optimise the coefficients of the weighted sum. Lasso applies an L^1 regularization penalty during training, which forces the coefficients of weakly predictive features exactly to zero. This inherent feature selection prevents the model from overfitting to the transient noise of historical regimes, ensuring it extracts only the fundamental, persistent drivers of price formation.

All data, where appropriate, were scaled and inputted into the lasso optimisation in per unit format such that linear model was trained in manner independent of scale. For instance, net demand was inputted into the model scaled by the peak demand for the model time frame. Therefore, the model learns that net demand at 10% of the overall peak is oversupply to normal market operation, whereas 70% of peaks means the market is in a state of system stress. Finally, the models were trained on the years 2019 and 2021 to replicate clam and volatile years, respectively. The linear model was blended with the merit order model using like years – i.e. the 2019 parameterisation of the merit order model and the linear model were aligned.

4.2.4 Stochastic Model

As the GB grid transitions to a high-variable renewable energy penetration system, extreme price volatility. This is characterised by deep negative pricing during periods of excess generation and severe scarcity pricing during low wind periods. To capture this, once the deterministic baseline determined by combining the merit order and statistical models, it is then stressed using an Ornstein-Uhlenbeck (OU) jump-diffusion process. The parameters of the OU process (mean reversion rate, volatility, jump intensity, and jump magnitude) were calibrated against the residual errors of the historically trained model – i.e. the error between the combined merit order and statistical models and the observed day ahead pricing. The OU process then generates a stochastic overlay representing market dynamics not captured by the blended day ahead price model. Applying this stochastic overlay via Monte Carlo simulation generates hundreds of highly realistic future price paths, fully evaluating the capture price resilience of the Tidal Lagoon under both calm (2019 regime) and volatile (2021 regime) conditions.

4.2.5 Commodity and Carbon Price Modelling

Commodity markets are difficult to model to any level of detail, therefore, to set future gas and hydrogen price the FES price trajectories [4] were utilised. The gas price was set by imposing the mean for the given scenario year on the daily gas price observed in the given historical regime. The hydrogen price was set as the production weighted average of the blue and green hydrogen price, with the blue hydrogen price being dependent on gas and carbon pricing and green hydrogen pricing being driven by electricity prices. A sensitivity on the parameter set associated with the green hydrogen pricing was undertaken and can be found in the *WP3 – Quantifying the Value of Tidal Lagoons* report. Carbon price setting was undertaken through the FES carbon price projections for the given future year.

4.2.6 Future Scenarios Modelled

Table X shows the set of simulation undertaken as the main study presented here – various sensitivity studies are shown and can be found in the *WP3 – Quantifying the Value of Tidal Lagoons* report. Simulations were taken coupling both the calm (2019) and the volatile (2021) model parameterisation years with the three main FES pathways for the years 2035 (calm and volatile) and 2050 (calm). For each model a type 1000 simulations were undertaken with and without the inclusion of the tidal lagoons – in this instance the lagoon capacity was removed from the offshore wind capacity to maintain a fixed generating capacity. This was done to gauge the impact of the lagoon as a predictable generating asset rather than studying the impact of additional generating capacity.

Simulation ID	FES Pathway	Scenario Year	Historic Regime	Gas Trajectory	H_2 Trajectory	Nuclear Avail.	Storage Duration
HT-35-19	Holistic Transition	2035	Calm (2019)	Low	Central	72%	4 hr
HT-35-21	Holistic Transition	2035	Volatile (2021)	High	Central	72%	4 hr
HT-50-19	Holistic Transition	2050	Calm (2019)	Low	Central	72%	8 hr
HE-35-19	Hydrogen Evolution	2035	Calm (2019)	Low	Low	72%	4 hr
HE-35-21	Hydrogen Evolution	2035	Volatile (2021)	High	Low	72%	4 hr
HE-50-19	Hydrogen Evolution	2050	Calm (2019)	Low	Low	72%	8 hr
EE-35-19	Electric Engagement	2035	Calm (2019)	Low	high	72%	4 hr
EE-35-21	Electric Engagement	2035	Volatile (2021)	High	high	72%	4 hr
EE-50-19	Electric Engagement	2050	Calm (2019)	Low	high	72%	8 hr

5 ENERGY SYSTEM AND ECONOMIC IMPLICATIONS

Under baseline conditions in 2035 in the 0-D model, NWTL produced 3.6 TWh/year with Andritz and 3.7 TWh/year with Tidetec, while the CTL and NTL showed slightly higher or lower values depending on the turbine type. Configuration optimisation significantly improved performance, with NWTL increasing output up to 6.3 TWh/year using Andritz turbines, and the CTL reaching 6.5 TWh/year with Tidetec.

The 2-D energy output results for the Tidetec turbine show a generally higher performance compared to the Andritz turbine, particularly for the CTL site. For the CTL, Tidetec starts at 4.4 TWh in 2035 and increases to 5.8 TWh in 2050, maintaining a stable output of 6.1TWh in both 2085 and 2135. This indicates a strong and sustained performance over time, with a notable improvement from mid century onwards. For NTL, the Tidetec turbine starts at 1.7TWh/year in 2035 and rises to 2.3TWh/year in 2050, reaching 2.4 TWh/year in 2085 and maintaining that level through 2135. Although this is lower than its CTL performance, it still shows a steady upward trend.

5.1 Flexible Operational Strategies

Further improvements were investigated through flexible operational strategies, which allow turbine operation, sluicing, and pumping to be dynamically adjusted according to tidal conditions. Flexible operation provided additional increases in energy output beyond configuration optimisation. [6]

Table 3. Optimised energy output of case study lagoons using flexible operation

Variable	Baseline	Configuration	Optimal (Andritz)
Andritz Turbine			
NWTL	3.6	6.3	7.3
CTL	3.9	4.4	5.2
NTL	2.9	3.0	3.1
Tidetec Turbine			
NWTL	3.7	5.8	6.6
CTL	3.7	6.5	6.5
NTL	2.4	2.8	2.9

NWTL and CTL show 15% and 18% generation improvement using these strategies. Gains for NTL (1%) were more limited due to constraints such as a smaller impoundment volume and restricted turbine capacity. For Tidetec turbines, improvements were also observed but were generally smaller in magnitude, suggesting that these turbines may already operate close to optimal efficiency under some site conditions. This exercise demonstrations energy production can increase without additional infrastructure, improving economic viability.

5.2 Climate Change Scenarios

Sea level rise has both positive and limiting effects on tidal range energy generation, depending on how it alters the tidal range. Using the Andritz turbine, the 2-D energy output results for both the CTL and NTL show a clear temporal trend influenced by projected sea level rise and evolving tidal dynamics. For the CTL, the electricity generation begins at 3.6 TWh/year in 2035 and increases to 4.9 TWh/year by 2050, indicating a period of enhanced generation potential. However, from 2085 onwards, the electricity generation stabilises at 4.8 TWh/year, suggesting that the system reaches a performance plateau under future conditions. Similarly, NTL starts with an electricity generation of 2.3 TWh/year in 2035, rising to 2.9 TWh/year in 2050. Like CTL, the output then levels off at 2.8 TWh/year for both 2085 and 2135.

These results reflect how the spatially resolved 2-D model captures the influence of changing hydrodynamic conditions over time, with initial gains in output followed by a stabilisation phase, likely due to the system adapting to long-term sea level and tidal regime changes. Insights into for the NWTL is limited to 0-D as a 2-D model was not developed.

5.3 Tidal Lagoon Revenue and Economic Performance

Tidal lagoon revenues were calculated using generation-weighted capture prices, defined as the average electricity price during periods when the lagoon generates power –Figure 4 shows a time series of the wholesale price along with the tidal generation profile for the **HT-35-19** and **HT-35-21** simulations. As well as revenue, the capture Price (Pcap) (the effective price received for generated electricity) and the cannibalisation factor (a comparison between capture price and average market price), were used to show the economic performance of the tidal lagoons. Figure 5 shows the capture price distribution across the principal simulations – we see that the capture price increases by ~1.7 times when moving from the calm to the volatile regimes in the 2035 scenarios, this was observed across the range FES pathways modelled. The capture price is significant reduced (~0.4 times the calm 2035 simulations) when moving to 2050 – prompted by the large increase in wind and solar capacity between 2035 and 2050 across all FES pathways. Across all simulations the cannibalisation factor was less than 5% meaning that at the levels of penetration simulated, tidal lagoons do not tend to cause price collapse as combined wind and solar often do. The economic performance indicators are summarised in Table 4.

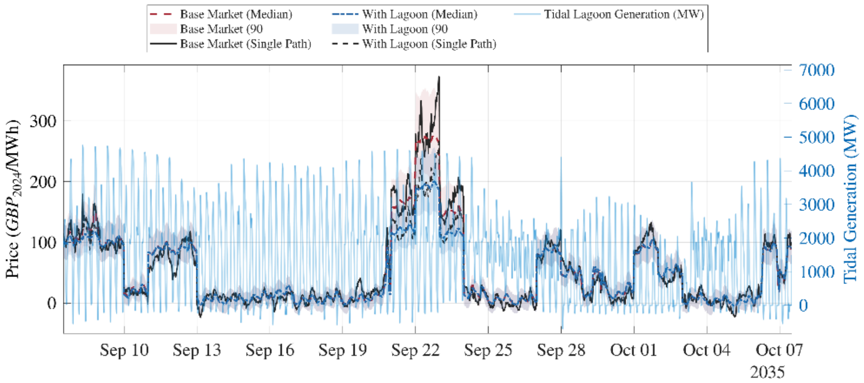
The simulation results for the 2035 scenarios demonstrate that wholesale price capture is temporarily viable option for funding tidal lagoons. In the 2035 Holistic Transition (2021 chaotic regime), the lagoon captures an expected £$_{2024}$95.59/MWh. Crucially, this high capture price is not sustained by a stable baseload of thermal generation, but rather by the severe thinning of the flexible dispatch stack, where under the Holistic Transition pathway there is aggressive retiring of highly efficient CCGTs, reducing unabated gas capacity to merely 5.4 GW, while expanding the weather-dependent renewable fleet to over 120 GW. Consequently, when meteorological wind droughts occur, the grid instantly exhausts its remaining cheap thermal capacity and is forced up the asymptotic scarcity curve—triggering expensive interconnectors, hydrogen peakers, and Demand Side Response (DSR) at extreme markups. Because the tidal lagoon's generation is dictated by deterministic lunar cycles rather than synchronous weather patterns, it regularly generates straight through these wind-driven supply shocks, perfectly capturing the violent scarcity premiums and inflating its average capture price.

However, the 2050 simulations explicitly reveal the difficulties of relying on pure merchant wholesale revenues for long-duration, high-CapEx infrastructure. As the NESO FES pathways aggressively expand zero-marginal-cost offshore wind and solar capacities, the frequency of zero-priced settlement periods dramatically increases. Consequently, the tidal lagoon's capture price collapses to as low as £$_{2024}$12.13/MWh (2050 Hydrogen Evolution, 2019 regime).

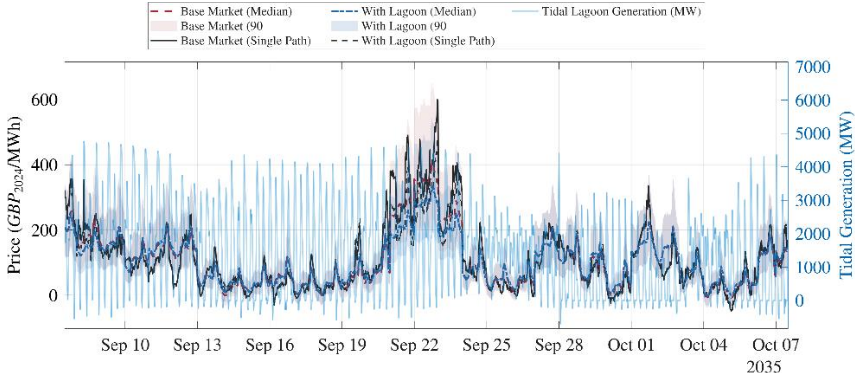
While the lagoon avoids self-cannibalization (maintaining a Cannibalization Factor near zero), it cannot escape the systemic deflation of the baseload price. At £12 to £16/MWh, the project cannot generate sufficient inframarginal rent to service the debt and equity yields required for multi-billion-pound civil engineering projects. As such these finding show support the clear consensus that tidal lagoons will required some market support in the form of CfDs or RAB status, see Section 6.

Table 4: Economic performance indicators for the tidal lagoons under the principle simulations.

Simulation ID	Annual Revenue [£millions]	Capture price [£]	Cannibalisation Factor [%]
HT-35-19	636	53.21	1.1
HT-35-21	1140	95.59	-0.4
HT-50-19	177	16.64	-1.7
HE-35-19	502	42.00	-1.2
HE-35-21	1115	93.21	-1.2
HE-50-19	128	12.13	-3.1
EE-35-19	539	45.00	-0.7
EE-35-21	1160	97.16	-0.7
EE-50-19	168	15.72	-2.3

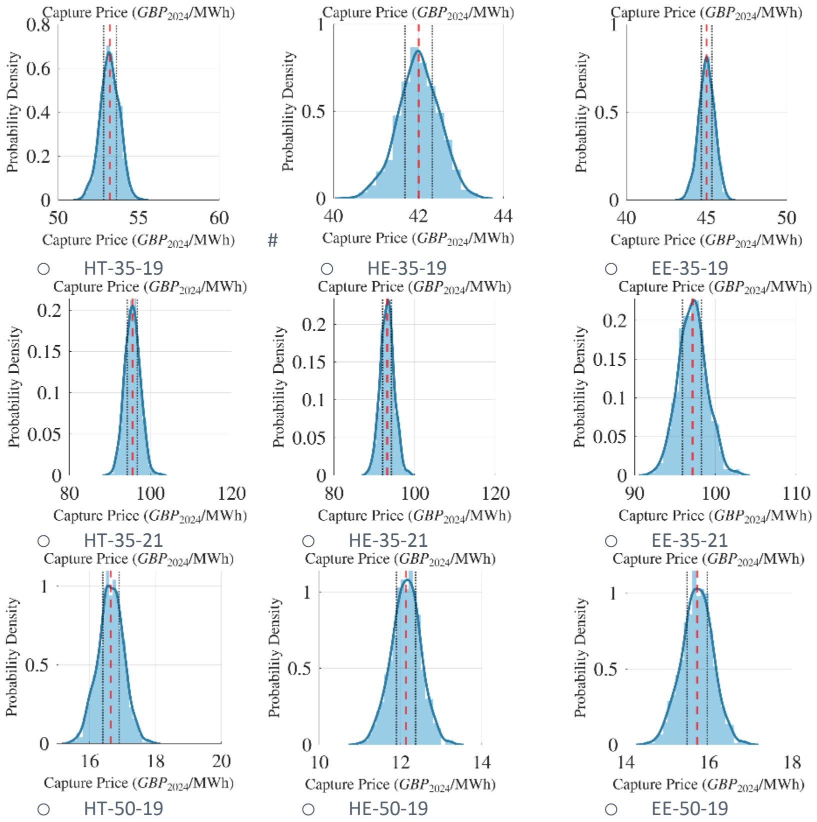


a. Calm (2019 regime) day ahead wholesale electricity price scenario and tidal lagoon generation 2035.



b. Volatile (2021 regime) day ahead wholesale electricity price scenario and tidal lagoon generation 2035.

Figure 4. Time-series comparing simulated day-ahead wholesale electricity prices, for the year 2035 under the Holistic Transition FES pathway. The prices shown are in GBP 2024, as adjusted via GDP inflation index. The range of the 1000 Monte-Carlo iterations are shown as the shaded regions, a 3-day smoothed median trace is presented, along with an example simulation path



○ HT-35-19 ○ HE-35-19 ○ EE-35-19

○ HT-35-21 ○ HE-35-21 ○ EE-35-21

○ HT-50-19 ○ HE-50-19 ○ EE-50-19

Figure 5: Distribution of the capture price associated with the tidal lagoon for the 9 principal simulations. The red trace shows the mean capture price and the dashed lines show the IQR.

5.4 Broader System and Market Impact

The broader system impact was gauged by considering price suppression (price reduction caused by tidal lagoons), scarcity peak shaving (reduction in extreme price spikes) and finally general volatility reduction impact on price stability, Table 5 shows the effects of tidal lagoon inclusion via these metrics. Figure 6 shows the simulated generation stack, demand and day ahead price for the **HT-35-21** simulation – between 21st September and the 23rd an instance of the tidal lagoon utility can be seen. During a 3-day wind draught the lagoon supports the stack, reducing the need for more expensive generators (in this case hydrogen) from generating thereby both shaving the peak price in the time frame observed and contributing to volatility reduction. This tendency can be seen in Table 5 where strong peak shaving and volatility reduction was observed during the volatile simulation.

Generally, the presence of the tidal lagoons within the market supported volatility reduction, the extent to which was dependent on the FES pathway and the time horizon, with significant reductions observed under the FES holistic transition pathway for the year 2035 but modest reductions elsewhere, Figure 7 shows the distribution of the volatility reduction tendency of the tidal lagoons for the main simulations outlined. Here we note the 3.9% volatility reduction in 2050 for the electrical engagement pathway which suggests that lagoons could support volatility reduction in 2050 and beyond depending on the specific distribution of generating capacity – although further modelling would be required to fully appraise this long-term benefit.

The peak shaving (reduction in the amount of settlement periods where price is greater than £300 (real 2024)) was significant in the near term (2035) for the holistic transition and the electrical evolution pathways but made no impact on the hydrogen evolution pathway and had minimal effect in 2050. However, the authors note that peak classification (set at £300) in this instance has a big impact on the findings.

Finally, the price suppression – how much the tidal lagoon lowers or raises the overall price – was not significant and in some instances even contributed to slightly higher electricity prices (as denoted by the negative values). Presumably this is because of the electricity consumed during pumping. There is room for improvement if the pumping strategy was optimised from a market participation perspective.

The findings overall suggest that tidal lagoons are generally positive in supporting improved market conditions for consumers, but their impact seems to diminish towards the 2050 FES pathway projections. However, differing scales of lagoon penetration may show greater benefits into the further future, more investigation here is required (particularly with broader operation optimisation).

Table 5: Table showing the broader system and market performance indicators.

Simulation ID	Price Suppression [£/MWh]	Peak Shaving [%]	Volatility Reduction [%]
HT-35-19	1.80	48.7	10.9
HT-35-21	-0.05	12.1	7.7
HT-50-19	0.10	0.0	0.8
HE-35-19	0.22	0.0	0.9
HE-35-21	-1.98	-0.6	0.8
HE-50-19	-0.03	0.0	0.2
EE-35-19	-0.05	29.1	1.8
EE-35-21	-2.17	-3.1	0.5
EE-50-19	0.29	0.0	3.7

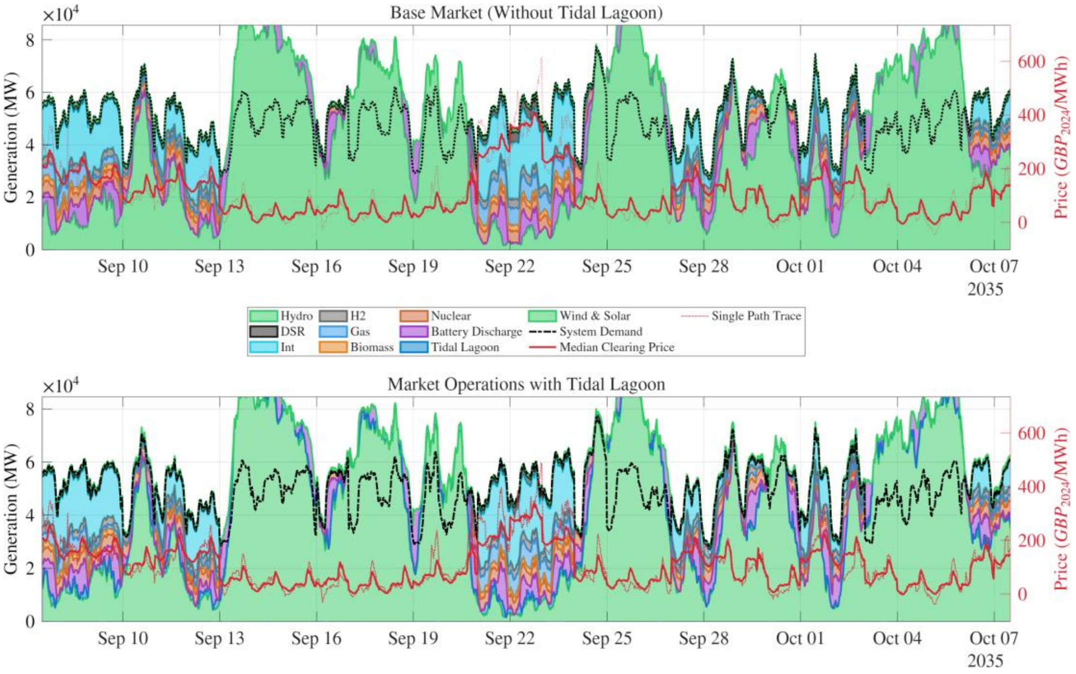
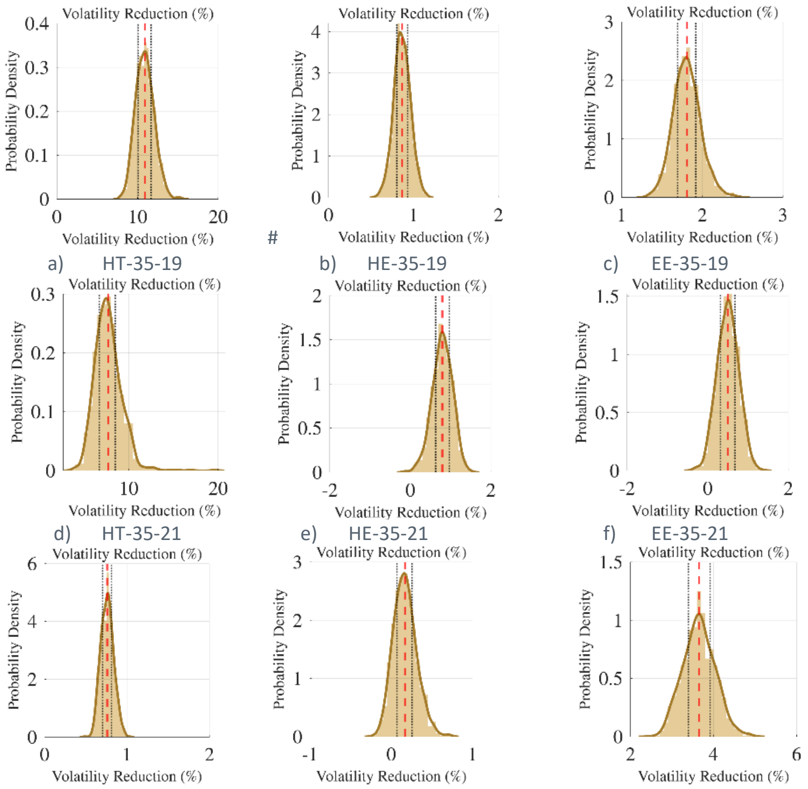


Figure 6: Timeseries of the differing generation stack, with demand and simulated day ahead clearing price overlayed for the **HT-35-21** (volatile) simulation. The solid red trace shows the median clearing price whereas the dotted red trace illustrate a single instance of the Monte-Carlo simulation.



a) HT-35-19 b) HE-35-19 c) EE-35-19

d) HT-35-21 e) HE-35-21 f) EE-35-21

g) HT-50-19 h) HE-50-19 i) EE-50-19

Figure 7: Distribution of the volatility reduction under the principal simulations. Here, the red dashed lines show the mean and the black dashed lines show the IQR.

6 FINANCING REVIEW

Tidal range projects present a distinct financial and commercial profile compared to other renewable technologies like offshore wind or solar. The return on investment forecast for tidal lagoons, largely based on a discounted cashflow analysis and Net Present Value, has so far not been convincing to UK Treasury and other key stakeholders. This section develops a model for the tidal range sector offering benefits over current support mechanisms.

The UK Government's primary renewable energy support mechanism is the Contract for Difference (CfD). While highly successful in driving down the cost of technologies such as offshore wind, the CfD framework is fundamentally misaligned with the economic reality of tidal lagoons. Under a CfD, the developer bears all the construction risk and cost overruns. This report assumes an 8 year construction timeline [7]. For a capital-intensive project, the compounding nature of interest of any debt incurred would be highly prohibitive for this construction timeline. Developers, and their investors, usually compensate for this high risk by demanding a higher cost of capital. With CfD support typically ranging 20 years (15 years prior to Allocation Round 7 in 2025-26), developers would attempt to recoup most of their investment within this short time frame. The higher cost of capital and this need to recoup investment in a short time span mean that strike prices incurred for such capital-intensive, long-term projects would be very high—ultimately resulting in a higher consumer subsidy cost.

6.1 Alternative Valuation Approaches

The Severn Estuary Commission Financial Report [8] considered other funding models, namely the Design, Build, Finance & Operate (DBFO) and Cap & Floor mechanisms. DBFO/PFI-style models are unsuitable because their typical 25–30 year contract lengths and lack of revenue support during construction do not match the long lifetimes and high upfront capital requirements of tidal range projects; moreover, the UK Government stopped approving new schemes under this model in 2018. The Cap & Floor mechanism is also not optimal as it only stabilises revenues once an asset is operational and does not cover construction-phase risk, leaving investors exposed to the significant build risks associated with tidal lagoon infrastructure.

6.2 Regulated Asset Base (RAB) justification

Under a RAB model, investors are permitted to earn a regulated return on their capital during the construction phase. By paying a small yield during the construction phase, the cost of compounded interest is eliminated. This significantly reduces the total capital that needs to be recovered during the asset's operational life. As the construction risk is shared, this typically allows the project to access the most economical pools of capital. Given the precedence of RAB models in backing large-scale, long-term and capital-intensive national infrastructure and helping to provide the lowest cost of capital, the RAB mechanism is the strongest option to take tidal range projects forward. As such, a modelling exercise was used to demonstrate the financial mechanics, cashflow profile and consumer protection mechanisms of funding a large-scale tidal range project using an RAB mechanism.

A RAB model determines a project's Allowed Revenue using a "building block" approach, which includes: a return on capital (based on the RAB and an agreed Weighted Average Cost of Capital (WACC), return of capital (regulatory depreciation that repays the investment over the asset's life), and operating expenditure (OPEX) to cover running costs. During construction, capital spending is added to the RAB and indexed to inflation to preserve investor value. Although sometimes viewed as offering guaranteed returns, RAB models include regulatory incentives and penalties—such as adjustments for CAPEX or OPEX overspending, plant availability, market performance, capacity delivery, and tax benefits—to ensure developers share risks and protect consumers from excessive costs.

6.3 Regulated Asset Base (RAB) Baseline Assumptions

A full methodology is available in the report 'FLOMAX TLC: Unlocking the technology through RAB financing'. To establish a baseline for a project operating without RAB support, an LCOE engine was run in parallel. Standard UK CfDs provide revenue certainty for 20 years, making a 120-year CfD forecast highly speculative. Therefore, the LCOE is used here simply as the theoretical breakeven price for a traditional project.

The following table outlines the core assumptions.

Table 6. Core assumptions for the regulated asset base model

Parameter	Assumption / Value
Project capacity	2,000 MW
Target CAPEX	£13.9 billion

Parameter	Assumption / Value
Construction period	8 years
Operational life	120 years
Annual energy production	5.37 TWh
Annual OPEX	£173.1 million (1.25% of CAPEX)
Plant replacement costs	£3.7 billion in years 40 and 80
Cost of capital (traditional/LCOE)	6.3% (FOAK hurdle rate)
Cost of capital (RAB)	2.5% (based on the Thames Tideway Tunnel precedent)
Penalty WACC during delays	1.5%
Investor overrun penalty	50% of CAPEX overruns removed from the RAB
Inflation indexation	2% annually

Costs adjusted to Q1 2026 prices. To test the robustness of this framework, the model evaluates four scenarios: Base Case, Cost Overrun, Schedule Delay, and Worst Case (overrun and delay). These assumptions were set to be much higher than the recommended Green Book Guidance for optimism bias on construction delay and capital cost overruns. [9]

Limitations of the model must be noted. The model uses a single WACC and excluding detailed financial components (e.g., debt–equity structure, tax treatment, and negotiated incentives) because key project-specific data are unavailable. As a result, it captures the core mechanics of a RAB framework but not the full financial complexity of a mature regulatory model.

6.4 Regulated Asset Base (RAB) Model Outcomes

Results show that while delivery failures increase overall costs, the RAB structure reduces the financing burden relative to traditional financing by lowering the cost of capital and smoothing revenue flows over time. Early revenue during construction avoids the large debt accumulation typical in privately financed infrastructure and distributes costs more evenly across generations of consumers.

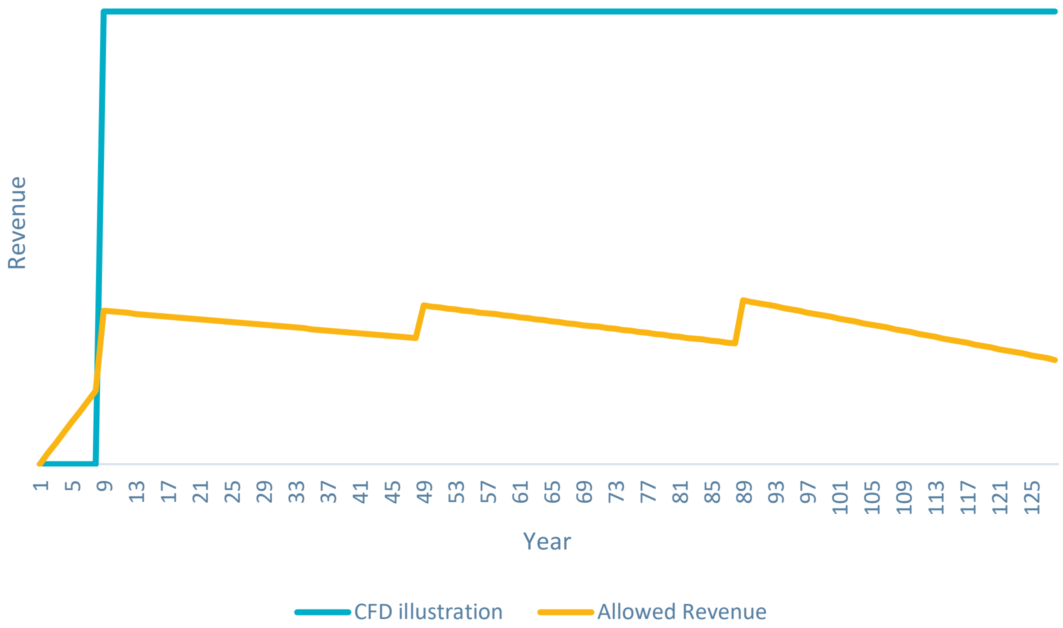


Figure 8: An illustration of the difference in cash flows between non-RAB and RAB-backed tidal lagoon projects.

Comparison to LCOE illustrates the profound cost penalty incurred when developers are forced to finance an 8 to 12 year construction phase entirely with private capital at a hurdle rate of 6.3%, devoid of the risk sharing benefits of an RAB for nationally important infrastructure. These values are based on assumptions in Table 6 and require in depth case by case analysis.

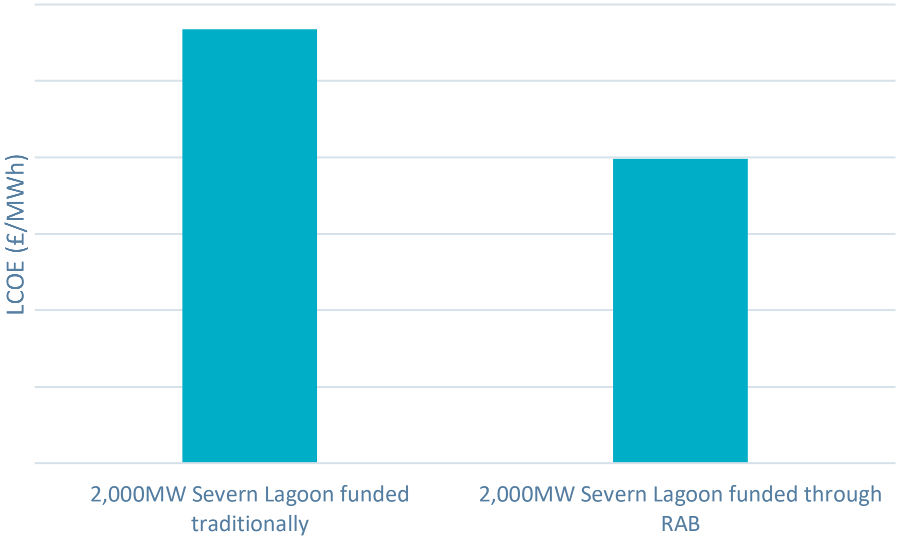


Figure 9: Comparing the LCOE of identical 2,000MW Severn Tidal Lagoon projects under a traditional financing scenario and with the RAB mechanism applied.

Risk sharing during construction means developers do not shoulder 100% of the risk; however, that means some risk is then transferred to the consumer, who ultimately pays for the mechanism through their bills. However, this risk can be managed through penalty and incentive mechanisms. This model demonstrates how penalty mechanisms can be implemented in RAB negotiations so that consumers so that any capital spend inefficiencies are not transferred solely to the consumer. This is summarised below.

Table 7. Impact of different delivery scenarios during construction on key stakeholders

Scenario	What Happens	RAB Mechanism Response	Implication for Consumers
Base Case (On time, on budget)	£13.9bn project delivered in 8 years. Under traditional finance, developers must carry full debt during construction with no revenue.	RAB allows returns during construction, preventing debt from compounding at high private financing rates.	Lower peak debt burden and lower long-term electricity cost compared with traditional financing. Demonstrates RAB's core advantage for large infrastructure.
Cost Overrun (On time, over budget)	CAPEX increases significantly beyond the £13.9bn baseline.	Efficiency penalty applied: 50% of cost overruns excluded from the RAB, meaning developers cannot earn returns on inefficient spending.	Consumers protected from full cost pass-through; developers share financial risk, incentivising cost discipline.
Schedule Delay (Delayed, on budget)	Construction extends from 8 to 12 years, delaying operations and revenue generation.	Penalty WACC applied during delay period, lowering the allowed return to investors.	Developers financially penalised for delays, ensuring risk sharing rather than transferring delay costs to consumers.
Worst Case (Over budget and delayed)	CAPEX rises by ~55% and construction is delayed by 4 years.	Both cost overrun penalties and delay WACC reductions apply. Developers lose a substantial portion of allowed returns.	Although total project cost rises, RAB forces developers to internalise part of the failure, limiting the cost increase passed to consumers.
Revenue Timing (Structural difference vs traditional models)	Traditional financing or CfD-style models provide no revenue during the 8–12 year construction phase.	RAB allows small consumer contributions during construction, smoothing cash flow and avoiding large debt accumulation.	Intergenerational cost sharing: avoids sharp electricity price spikes after commissioning and spreads costs over the asset's long life.
Consumer Protection Mechanism	Cost overruns or inefficiencies increase the asset base during construction.	Upon operation, penalties reduce the allowable RAB, lowering the return developers can earn.	Ensures inefficient capital spending is not fully transferred to consumers, reinforcing accountability within the RAB framework.

7 INNOVATION AND STRATEGIC INSIGHTS

7.1 Operational Insights

The report evaluates how tidal lagoon generation influences wholesale electricity prices by analysing simulated market outcomes across multiple future scenarios and stochastic price paths. Because tidal generation is predictable and partially dispatchable, it can alter the timing and magnitude of generation during periods of system stress.

Table 8. Impact on electricity pricing and operation based on model outcomes

Impact Area	Explanation
Scarcity peak shaving	Tidal generation helps reduce the frequency and severity of extreme price spikes during periods of tight electricity supply. By adding generation capacity at these times, lagoons reduce reliance on expensive peaking plants and help mitigate scarcity pricing events.
Capture price dynamics	The revenue for tidal lagoons depends on the capture price, which is the average wholesale electricity price during the periods when the lagoon generates power. Because tidal output often coincides with high demand periods, the capture price can remain competitive compared with the overall average system price.
Cannibalisation effects	As with other low-marginal-cost generation technologies, increasing tidal deployment can lower electricity prices during the periods when it generates power. This is measured using a cannibalisation factor, which compares the capture price of the technology with the overall market average price.

7.2 Supply Chain and Innovation

In addition, the project team reviewed broader industry insights and developments to inform future recommendations for research projects, summarised below, and in detail in Report Work Package 5 – Enhancing tidal lagoon scheme value to the UK supply chain.

7.2.1 Industrial and Regional Opportunities

The construction and deployment of tidal lagoon infrastructure present significant opportunities for industrial development, regional manufacturing capacity, and supply chain growth. Civil engineering components such as large concrete caissons, turbine housings, and breakwater structures require specialised fabrication facilities capable of producing extremely large pre-cast structures. Although such facilities do not currently exist in the UK at the required scale, the development of multiple tidal lagoon projects could justify investment in dedicated caisson manufacturing infrastructure, creating new industrial capabilities and skilled employment opportunities. Interviews were conducted with project developers, material suppliers and engineering firms across the South Wales Industrial Cluster which identified both appetite and capability to respond to both floating offshore wind and tidal range projects in parallel, and synergistic quayside facility requirements. This an opportunity to capitalise o

7.2.2 Demonstration and Piloting

One of the biggest barrier to any innovation in offshore technologies is always the cost of demonstration, verification and validation [10]. Welsh Government could prioritise the funding, development and operation of a test and demonstration facility for tidal lagoon turbines. Such a facility could avoid major capital costs by leveraging existing, under-utilized infrastructure, like docks or basins, to advance innovation, capture the benefit of these innovations in larger tidal range developments, and provide investor confidence in novel and emerging technologies. We have proposed the Aberthaw Power Plant site as a potential candidate due to its favourable tidal range and proximity to existing industrial resources, and its credentials as a potential site for the first commercial lagoon project in the Severn Estuary.

7.2.3 Technology Developments

Several emerging engineering and materials innovations could significantly improve the performance, sustainability, and durability of tidal lagoon infrastructure. Advances in low-carbon concrete such as the use of supplementary cementitious materials (SCMs) - ground granulated blast-furnace slag, fly ash, calcined clays, and other substitutes can reduce the clinker content of cement and substantially lower CO_2 emissions. Additional techniques such as CO_2 injection during concrete mixing and CO_2-cured non-Portland binders offer further potential for carbon reduction and even partial carbon sequestration in concrete structures. Digitalisation of concrete design and construction processes also presents opportunities to reduce material use and emissions. Advanced modelling tools enable optimisation of structural geometry, the incorporation of voids or low-strength infill materials, and improved material specification, potentially reducing the required volume of structural concrete by up to 50%. Optimised designs can also balance concrete strength, reinforcement requirements, and structural dimensions to minimise embodied carbon.

Innovations in reinforcement materials offer additional benefits for marine structures. Alternatives such as Basalt Fibre Reinforced Polymer (BFRP) and Glass Fibre Reinforced Polymer (GFRP) provide higher tensile strength than conventional steel reinforcement and are highly resistant to corrosion in saline environments. Their lighter weight reduces transport emissions and construction complexity, while corrosion resistance allows for reduced concrete cover, lowering overall material demand.

Modern construction methods, particularly pre-cast concrete caissons, represent a key engineering innovation for tidal lagoon development. Caissons can be manufactured onshore in controlled environments and transported to site for installation, reducing offshore construction complexity and improving quality assurance. Although emerging technologies such as 3D printing of concrete structures offer future potential for material efficiency and automation, they are currently better suited to complex smaller structures rather than large-scale lagoon components.

Significant technological development is also occurring in tidal turbine design. The established Kaplan bulb turbine, such as the triple-regulated Andritz turbine, incorporates adjustable blades, guide vanes, and variable-speed generators to maximise efficiency across varying tidal heads. New designs aim to further enhance performance and environmental compatibility. For example, the Tidetec rotating turbine uses a turret system that aligns the turbine with tidal flow, enabling equal efficiency during both ebb and flood tides. The Jacobs very-low-head contra-rotating turbine uses sequential counter-rotating rotors to improve efficiency under extremely low head conditions while reducing turbulence and potential impacts on marine life. These technologies remain at demonstration stage but could significantly improve power generation efficiency and environmental performance in future tidal range projects.

Storage solutions such as lithium-ion battery systems, liquid air or compressed air energy storage, pumped hydro storage, and hydrogen production through electrolysis could be integrated with tidal generation to balance supply and demand. These technologies support grid stability and create additional industrial activity in emerging clean-energy sectors, and could also be tested at demonstration scale alongside tidal range energy.

8 CONCLUSIONS AND RECOMMENDATIONS

Hydrodynamic modelling shows that large-scale tidal lagoons can produce substantial electricity generation. Baseline annual outputs of around 3.6–3.9 TWh can be increased significantly through design optimisation and flexible operation, with some sites achieving up to 6.3–6.5 TWh per year. Operational optimisation alone increases generation by 15–18% at certain sites, illustrating the importance of flexible control strategies for maximising energy output.

Electricity market modelling indicates that tidal lagoons can generate significant and resilient revenues. Across the 2035 scenarios analysed, annual revenues range between approximately £500 million and £636 million in calm market conditions, and increase to over £1.1 billion in volatile market conditions characterised by higher scarcity pricing. Capture prices vary between approximately £42/MWh and £53/MWh in calm regimes, rising to around £93–£97/MWh under volatile market conditions.

A key finding of the study is that tidal lagoons exhibit minimal cannibalisation effects, with capture prices remaining within 5% of the average market price across the scenarios modelled. This indicates that tidal generation does not significantly reduce electricity prices during its own production periods and therefore maintains relatively stable revenue compared with other low-marginal-cost renewable technologies.

Beyond project-level revenues, tidal lagoons also provide broader system benefits. The modelling demonstrates that tidal generation can reduce the frequency of extreme price spikes, with scarcity peak events above £300/MWh reduced by up to 48.7% in some scenarios. In addition, tidal lagoons contribute to electricity price volatility reductions of up to 10.9%, supporting greater stability in electricity markets with high levels of renewable generation.

However, the study confirms that financing structures remain a critical factor for enabling tidal lagoon deployment. Traditional project financing models require developers to bear the full construction risk during an extended build period, resulting in higher financing costs. The analysis suggests that a Regulated Asset Base (RAB) framework could significantly reduce these costs by lowering the cost of capital, while distributing costs more evenly across the asset’s 120-year operational lifetime.

In addition to energy system benefits, tidal lagoon development could stimulate significant industrial and regional economic opportunities. The construction of large marine structures and associated infrastructure could support the growth of domestic manufacturing capabilities, strengthen supply chains for marine renewable technologies, and create skilled employment in coastal regions.

Table 9. Stakeholder benefits based on model outcomes

Stakeholder	Impact	Description
Project Developer / Operator	Revenue optimisation through price-aligned generation	Flexible operation allows turbine dispatch to shift within the tidal cycle, enabling generation during higher wholesale electricity price periods. Because lagoon revenue depends on

Stakeholder	Impact	Description
		the generation-weighted capture price, this improves the average price received for generated electricity.
	Increased operational control via pumping	Pumping capability enables operators to adjust lagoon water levels and better align generation with favourable market conditions, increasing operational flexibility.
	Improved revenue resilience	By targeting higher-price generation periods and reducing exposure to low-price periods, flexible operation can improve the average capture price and stabilise project revenues.
Consumers	Reduction in price spikes	Flexible lagoon operation allows generation during periods of tight system margins, reducing the frequency and magnitude of extreme price events (scarcity peak shaving). This lowers consumer exposure to very high wholesale electricity prices.
	Reduced price volatility	Lagoon generation smooths electricity supply during high-demand periods and reduces reliance on expensive marginal generators, contributing to lower overall price variability in the electricity market.
Electricity System	Contribution to system reliability	Tidal lagoons provide predictable and forecastable generation within the electricity system dispatch stack, supporting system stability when integrated with other renewable and flexible generation technologies.

While further research and demonstration will be required to refine technologies and reduce project risks, the findings of this project indicate that tidal lagoons would provide long-term strategic value to the UK energy system. Continued progress in turbine technology, operational optimisation, infrastructure innovation, and financing mechanisms will be essential to unlock the full potential of tidal range energy.

Building on the findings from this study, several areas for future work are recommended to enhance the understanding and viability of tidal lagoon energy systems as detailed below.

1. **Expansion of 2-D Modelling to NWTL**

While this study has incorporated 2-D hydrodynamic modelling for the CTL and NTL lagoons, the NWTL has only been assessed using 0-D modelling. Given the significant improvements in accuracy and spatial resolution offered by 2-D models, it is recommended that this approach is extended to the NWTL.

2. **Expand Study for Other Potential Sites**

This study has focussed on three case studies, NWTL, CTL and NTL, however, there are several other potential locations in Wales (and other parts of the UK) with a significant potential for tidal lagoon development which could benefit from the modelling work undertaken as part of this project. For example, both the 0-D and 2-D models can easily be updated to assess the energy potential at other locations in the Severn Estuary and Bristol Channel, and beyond.

3. **Integrated Financial, Economic and Environmental Assessment**

Future work should incorporate a comprehensive financial analysis to evaluate the economic feasibility of each lagoon scheme. This includes:

- Revenue Forecasting: Based on energy yield projections under various operational and climate scenarios—including potential income and energy pricing from grid services or energy storage integration—the forecasting results help identify key factors such as energy demand, time-of-day variations, and the contribution of renewables in meeting that demand. These insights are derived using flexible operation schemes within the GA-0-D model.
- Cost-Benefit Analysis: Comparing the long-term benefits of flexible operation and configuration optimisation against their associated costs in an improved 0-D model. The modelling suggests that price suppression impacts are modest and sometimes negative, potentially due to suboptimal pumping strategies. Further investigation on the role of pumping optimisation could quantify how improved operational optimisation affects both system and revenue outcomes.
- Environmental impact: The current study focusses on energy generation; however, other factors are important to consider, including the incorporation of environmental impact modelling (e.g. habitat changes, changes to sedimentation patterns, water quality, etc). This is particularly important for gaining regulatory approval and public support. Coupling 2-D modelling with environmental impact models could provide a more holistic evaluation of tidal lagoon effects.

4. Investment into Innovation

Value can be captured through development and demonstration of key innovation areas outlined in Section 7, including new turbine design, advanced materials, modern construction and modularisation. We recommend this activity is centred around the proposed Aberthaw demonstration asset.

5. Application of RAB Mechanism

The current analysis is based on theoretical, system-level assumptions and does not yet reflect the commercial and regulatory complexity of implementing a RAB model in practice. Developing an appropriate RAB structure would require extensive negotiation between developers, investors, regulators, and consumers to agree on risk allocation, returns, and cost recovery mechanisms. As such, further project-specific work is needed to translate these findings into a practical and investable financing model.

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