LEVELISED COSTS OF POWER FROM TIDAL LAGOONS

A report to Tidal Lagoon Power plc

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HEADLINES

- Tidal lagoon power projects could be cheaper than offshore wind and some could be cost comparable to nuclear generation (based on Tidal Lagoon Power's capital and operating cost estimates for tidal lagoons, and DECC's levelised costs for other technologies).
- Our assessment of the central value for the required CfD strike price for the first three lagoons studied on a volume-weighted average basis is £111/MWh (assuming a 35-year CfD duration). Lagoon 1 is £168/MWh, whilst for Lagoons 2 and 3 this falls to £130/MWh and £92/MWh respectively.
- The reduction in required strike prices in moving from Lagoon 1 to Lagoon 3 is driven primarily by moving to bigger sites with greater tidal range rather than on an assumption of technology learning.
- The levelised cost of electricity for the first three lagoons on a volume-weighted basis is £100/MWh. The cheapest of the lagoon projects studied, Lagoon 3, has levelised costs broadly similar to DECC's assessment of the cost of onshore wind, large scale solar PV, nuclear and gas-fired generation.
- When compared at a social discount rate of 3.5%, a rate commonly used by Government to evaluate the future costs and benefits to consumers of policy decisions, even Lagoon 1 is cost comparable with offshore wind, and on this basis Lagoons 2 and 3 would be cheaper than a gas-fired power station.
- The initial lagoon project will require support of around £50m per year, which is small compared to the Government's budget for total low-carbon electricity support of around £7.6bn per year by 2020. This relatively low level of support is justified as it creates the option to develop the larger and cheaper projects in the pipeline.
- Tidal lagoons have an assumed operating life of 120 years. This very long asset life means a tidal lagoon will be generating low cost renewable electricity long after CfD expiry, and consumers will continue to benefit from this cheap electricity for many years.
- Tidal lagoon power adds diversity to the low-carbon generation mix. Supporting tidal lagoon power, which The Crown Estate estimates could contribute up to 25TWh of renewable electricity per year, would help to reduce the overall risk of deploying sufficient low-carbon generation to meet the UK's longer term energy security and environmental goals.

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EXECUTIVE SUMMARY

Tidal range power is a renewable electricity technology which uses the rise and fall of tides to generate electricity. As tides are predictable, this results in a reliable supply of renewable electricity with a known output profile. Tidal range power is not a new technology, with several tidal barrage schemes in existence worldwide. Tidal lagoons are a new and potentially more environmentally benign tidal range power configuration.

Tidal Lagoon Swansea Bay plc is developing a 320MW tidal lagoon power project in Swansea Bay, with a target date for first electricity generation in the second half of 2018. The Swansea Bay project is the first of a pipeline of tidal lagoon power projects identified by the parent developer Tidal Lagoon Power plc (TLP), with five subsequent full-scale lagoons at various stages of development which could be in operation by 2023. TLP anticipates that the total potential electricity output from this pipeline could match or exceed 25TWh/year (The Crown Estate's estimate of tidal lagoon potential), equivalent to around 8% of UK electricity demand.

The UK Government is introducing a new support mechanism for low carbon generation to incentivise deployment of renewable and other low-carbon technologies. This involves entering into Feed-in Tariff Contracts for Difference (CfD FiTs) with eligible projects, whereby electricity market revenue is 'topped-up' to a pre-defined 'strike price'. The UK Government has stated that the required CfD strike price for Tidal Range will be determined on a project by project basis, acknowledging the large variance in costs depending on the tidal characteristics of each potential site. Hence strike prices for tidal lagoon projects will essentially be determined on a case-by-case basis and there is an opportunity for TLP to demonstrate to the Government the costs of its pipeline of lagoon projects.

The objective of this study is to provide an assessment of the economics of tidal lagoon power for three specific projects in the TLP pipeline, including the Swansea Bay project. The study draws on technical cost data supplied by TLP, translating this into an assessment of lifetime generation costs ('referred to as the 'levelised costs of energy' or LCOE) and of likely CfD strike prices required. In calculating levelised costs and required strike prices we follow as far as possible the approach used by DECC for other technologies, with input assumptions based on the EMR Delivery Plan, enabling a fair comparison between technological competitors.

Key outcomes and messages

The energy cost of tidal lagoon projects is competitive with other low-carbon technologies

Our analysis shows that the first project (in Swansea Bay) is relatively expensive but later projects are cheaper than offshore wind and comparable to nuclear generation. The central value we derive for the LCOE of Lagoon 1 is approximately £150/MWh, while for Lagoons 2 and 3 this falls to around £120/MWh and £90/MWh respectively. The cheapest of the lagoon projects assessed, Lagoon 3, has levelised costs broadly similar to onshore wind and large scale solar PV, considered to be among the more established (and cheapest) renewable energy technologies, and also nuclear and gas-fired generation.

On a portfolio basis the three tidal lagoon projects delivers a volume-weighted average LCOE of around £100/MWh, owing to the much larger size of the later projects compared to the first. This level of LCOE indicates that a pipeline of tidal lagoon projects could be a cheaper low-carbon alternative than offshore wind (even accounting future reductions in offshore wind costs), and could have costs broadly in the same range as nuclear power stations.

The anticipated reduction in offshore wind strike prices over time is based on an assumption that capital and operating costs will reduce through technology learning and investor hurdle rates will decline as the technology matures. In contrast, the reduction in levelised costs in moving from Lagoon 1 to Lagoon 3 is driven primarily by moving to bigger sites with higher tidal range and does not rely on an assumption of technology learning.

A pipeline of projects could be supported through strike prices in line with those announced in DECC's first delivery plan

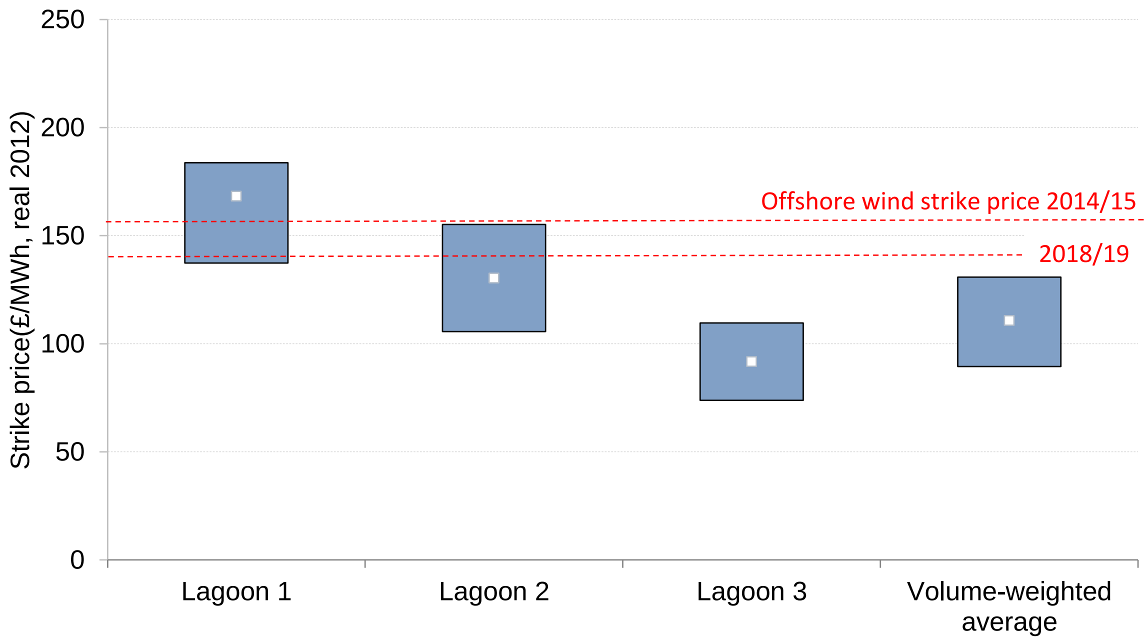
The CfD strike price for offshore wind announced in the EMR Delivery Plan is £155/MWh for projects commissioning in 2014/15, decreasing to £140/MWh by 2018/19. Based on our analysis, whilst Lagoon 1 requires a strike price above offshore wind, Lagoon 2 is competitive with offshore wind and Lagoon 3 is significantly cheaper.

Our assessment of the central value for the required CfD strike price for Lagoon 1 is around £168/MWh, while for Lagoons 2 and 3 this falls to around £130/MWh and £92/MWh respectively. These results are based on the key assumptions of a 35-year CfD contract followed by full commercial exposure to the wholesale electricity price. The 35-year length of CfD contract is justified on the basis that the project lifetime is twice the length of nuclear, which has a 35-year CfD duration. Like nuclear, a tidal lagoon project offers low-carbon electricity for a much longer period than an offshore wind project.

The volume-weighted average central strike price for the three lagoons is around £111/MWh, offering the potential for renewable electricity considerably lower than the strike prices for offshore wind, quickly and at scale (Figure 1). Also, supporting tidal lagoon power has minimal impact on the Levy Control Framework budget to 2020/21.

There will always be uncertainty associated with a study addressing the costs of future projects. In this study we address this uncertainty by examining ranges of cost estimates and by performing sensitivity analyses. The main drivers of uncertainty in our strike price calculation for tidal lagoon power include construction costs, construction delays and the risk premium required by investors.

Figure 1 – Required strike price for tidal lagoon projects



The central estimate is marked by white box, the bar range shows variance on capex assumption.

Additional benefits of tidal lagoon power

Like wind and solar, tidal lagoon power does not generate electricity 'baseload', and other capacity will be required to provide electricity when the tide is turning. However, the timing and amplitude of tides can be determined years ahead of time, and so the output of a tidal lagoon generator can be considered predictable. The requirement for back-up capacity will be known in advance and so its provision can be planned and optimised in advance. This contrasts with offshore wind, where there is inherent uncertainty in wind forecasts. Because high and low tides occur at different times around the coastline, then a portfolio of appropriately-sited tidal lagoons would have a much smoother generation profile than a single lagoon, thus reducing the requirement for back-up generation from other sources.

Tidal lagoons are long-life assets, with an assumed operating life of 120 years. This compares to offshore wind, where the operating life is generally assumed to be in the range 20-25 years and nuclear at 60 years. This very long asset life means a tidal lagoon will be generating low cost renewable electricity long after CfD expiry, and consumers will continue to benefit from this through low wholesale electricity prices.

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1. INTRODUCTION

1.1 Background

Tidal lagoon power is a renewable electricity technology which uses the rise and fall of tides to generate electricity. A ‘lagoon’ is created by building a breakwater around an area of sea bed, for example in a bay. Hydroelectric turbines are installed in the breakwater, and these generate electricity as water enters the lagoon on a rising tide and exits it during falling tide. As tides are predictable, this results in a reliable supply of renewable electricity with a known output profile.

Tidal range power is not a new technology. In France, a scheme has been operating at La Rance in Brittany since the 1960s. The largest scheme in the world is the 254MW Sihwa Lake Tidal Power Station in South Korea, opened in 2011, and a number of other smaller schemes are in operation around the world. The construction of a lagoon to harness power from tidal range however is new as the existing schemes have all been barrage schemes across river estuaries.

Tidal Lagoon Swansea Bay plc is developing a 320MW tidal lagoon power project in Swansea Bay. The company aims to begin construction in the first half of 2015 with first power generation in the second half of 2018. The Swansea Bay project is the first of a pipeline of tidal lagoon power projects identified by the parent developer Tidal Lagoon Power plc (TLP), with five subsequent full-scale lagoons at various stages of development which could be in operation by 2023. TLP anticipates that the total potential electricity output from this pipeline could match or exceed 25TWh/year (The Crown Estate’s estimate of tidal lagoon potential[1]), equivalent to around 8% of UK electricity demand[2].

The UK Government has committed to challenging environmental goals. Under the EU Renewable Energy Directive, 15% of the UK’s energy consumption must be sourced from renewable sources by 2020, compared to around 4% in 2012. The Climate Change Act sets a legally binding target of reducing UK greenhouse gas emissions by 80% (compared to 1990 levels) by 2050. Renewable electricity will play a key role in meeting these goals, and a range of renewable electricity technologies will be required. Power from tidal lagoons has the potential to make a significant contribution to the UK’s longer term environmental objective.

The UK Government is introducing a new support mechanism for low carbon generation to incentivise deployment of renewable and other low-carbon technologies. This involves entering into Feed-in Tariff Contracts for Difference (CfD FiTs) with eligible projects, whereby electricity market revenue is ‘topped-up’ to a pre-defined ‘strike price’. The strike price will vary by technology and year of commissioning.

The Government has recently announced strike prices for projects commissioning in the period 2014/15 to 2018/19[3]. No strike price has been announced for tidal range (including tidal lagoon and tidal barrage) projects, and the CfD strike price (and contract duration) will be determined on a case by case basis. This reflects the fact that the costs of such

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1 *UK Wave and Tidal Key Resource Areas Project*, The Crown Estate, October 2012

2 Based on final consumption of electricity in 2012 at 318 TWh, DUKES 2013, DECC

3 *Electricity Market Reform Delivery Plan*, DECC, December 2013. Since publishing that document, DECC has announced that strike prices for ‘established’ technologies such as onshore wind and solar PV will be set by competitive auction.

projects are site specific, and there is little information in the public domain about what these costs might be. Hence strike prices for tidal lagoon projects will essentially be determined through discussions between project developers and Government.

There is an opportunity for TLP to demonstrate to the Government the costs of its pipeline of lagoon projects and how this pipeline can contribute to the UK's environmental commitments.

1.2 Objective of this study

The objective of this study is to provide an assessment of the economics of tidal lagoon power. The study draws on technical cost data supplied by TLP, translating this into an assessment of lifetime generation costs ('referred to as 'levelised costs') and of likely CfD strike prices required. We also compare these to other low carbon technologies, in particular offshore wind, which is seen as the marginal technology required to meet the UK's renewables target.

1.3 Overview of approach and limitations

We examine three projects in TLP's project pipeline. The first, "Lagoon 1", is the Swansea Bay scheme. "Lagoon 2" and "Lagoon 3" are other, larger, projects at an earlier stage of development, in different parts of the UK. They are considered to be representative of a pipeline of multiple projects whose exact locations are commercially sensitive. We have not examined TLP's full project pipeline but we understand that "Lagoon 2" is not the smallest project in this pipeline, nor is "Lagoon 3" the largest.

For each project we calculate two metrics:

- The levelised cost of electricity (LCOE). This is a measure of the lifetime cost of electricity produced by a power station, taking into account both capital and operating costs, plus the investor's return on investment. LCOE is commonly used by policy makers to compare different technologies.
- The required CfD strike price. This is related to the LCOE because more expensive technologies require more financial support. However it is different from (and generally higher than) the LCOE because it takes into account CfD contract length (which is shorter than the asset operating life) and certain other costs associated with trading the electrical output.

The levelised cost of tidal lagoon project development is site specific and as a result so too is the required level of Government support. It is therefore useful to calculate these metrics as a volume-weighted average for the portfolio of the three lagoons we analysed as a whole. This gives the reader an easier metric with which to compare other competing technologies. In calculating levelised costs and required strike prices we follow as far as possible the approach used by DECC for other technologies, with input assumptions based on the EMR Delivery Plan or other DECC documents where available.

In order to determine some of the input assumptions to the levelised cost calculation (for example capex and opex costs), TLP provided us with a copy of their financial model for the three lagoon projects. Note however that the scope of this study did not include a detailed review of that model. We understand the engineering costs provided within it to be based upon budget pricing with some cost engineering assumptions but have not determined the validity of these assumptions for the purposes of this study.

There will always be uncertainty associated with a study addressing the costs of future projects. For technology costs there is the uncertainty associated with costing a project today – for example engineering feasibility studies will typically quote a wide uncertainty range on capital cost estimates. There is also uncertainty in future operating costs, in project lifetime, and in the rate of return required by investors. Whilst Tidal Lagoon Swansea Bay has already devoted considerable effort to reducing these uncertainties – for example through discussions with equipment providers – some uncertainty inevitably remains. The level of uncertainty is greater for Lagoons 2 and 3, which are at an earlier stage of development. In this study we address this uncertainty by examining ranges of cost estimates and by performing sensitivity analyses.

1.4 Structure of this report

Chapter 2 and Chapter 3 provide a quantitative analysis of the levelised cost and strike price calculation for tidal lagoon power and compares the results with other low carbon technologies. Chapter 4 provides a qualitative analysis of other potential benefits of tidal lagoon power not immediately apparent in the calculation of strike prices.

1.4.1 Conventions

All monetary values quoted in this report are in GB Pounds Sterling in real 2012 prices, unless otherwise stated. This allows easy comparison with strike prices published by DECC for other technologies, which are on the same basis.

1.4.2 Sources

Unless otherwise attributed the source for all tables, figures and charts is Pöyry Management Consulting.

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2. COMPARISON OF ENERGY COSTS

The levelised cost of electricity (LCOE) is a standard measure that enables comparison of costs of projects utilising different underlying technologies. It is a measure of the lifetime cost of generation of a power station, taking account of its capital and operating costs, as well as the need for investors to make an appropriate return.

In this chapter we explain the methodology behind the levelised cost calculation, present our input assumptions for the tidal lagoon projects and finally draw comparison with other low carbon technologies.

2.1 The levelised cost calculation

The LCOE of a power station project is determined by constructing a discounted cash-flow model and solving for the levelised cost value which delivers the target return:

$$LCOE = \frac{\sum_{i=0}^{N} \frac{C_i}{(1+r)^i}}{\sum_{i=0}^{N} \frac{V_i}{(1+r)^i}}$$

where: C_i is the cost in year 'i' (capital and operating costs) (£);
V_i is the power output in year 'i' (MWh);
r is the required rate of return (%) or 'discount rate'; and
N is the plant lifetime (years)

We have constructed a levelised cost model that takes account of different input project assumptions and enables us to consider uncertainty around each assumption through using central, low and high values. Section 2.2 explains in greater detail the main input assumptions used to calculate our LCOE for the three tidal lagoons.

2.2 Input assumptions

Most of the input cost assumptions used to calculate the LCOE for the three tidal lagoon projects have been derived from a financial model provided by TLP. We have not completed an independent engineering review of these costs but we understand that these are based on a reasonably detailed bottom-up costing of the Swansea Bay project utilising both internal engineering capability and external engineering project partners. External partners who have contributed to engineering design and detailed costing include Atkins Global, Van Oord, Costain Group, KGAL Consulting Engineers, GE and Alstom. The power output estimates have been calculated by an expert modelling team from Liverpool University and validated by HR Wallingford. Many elements of the capital and operational costs have been identified upon receipt of fixed price bids to complete elements of the work. These bids will be subject to a competitive bidding process. TLP has added a contingency to these estimates and considers the central values provided to be conservative in nature. The cost estimated for Lagoons 2 and 3 are less certain, but have been informed by the Swansea Bay experience and location-specific costing estimates from external engineering project partners. The central values for the key input assumptions used in our analysis are summarised in Table 1.

Table 1 – Central levelised cost input assumptions

Input assumption - central	Units	Lagoon 1	Lagoon 2	Lagoon 3
Installed capacity	MW	320	1500	1800
Net annual power output	GWh	495	2512	4112
Construction time	years	3	4	4
Construction period		2015 - 2018	2016 - 2020	2017 - 2021
Capital cost	£/kW	2853	2370	2338
Total capital cost	£m	913	3555	4209
Capex phasing	%/year	45/30/25	35/30/25/10	35/30/25/10
Operating cost	£/kW/year	31	20	18
Total operating cost	£m/year	9.8	29.5	33
Discount rate (pre-tax, real 2012)	%	6.5%	6.5%	6.5%

Source: Pöyry interpretation of Tidal Lagoon Swansea Bay financial model

Levelised cost estimates are highly sensitive to the input assumptions used in its calculation. For tidal lagoons the key sensitivities are the assumptions made for capital cost, construction time and discount rate. For other technologies the levelised cost requirement can also be sensitive to fuel and carbon costs, operating costs and load factor.

2.2.1 Capital cost and build time

The overall capital cost figure presented in Table 1 for each lagoon project includes cost estimates for design and development, regulatory and licensing, construction, and all supporting infrastructure requirements. The capex for each project includes a defined length of sea wall to create the lagoon, a specified number of electrical turbines and all supporting civil, electrical and mechanical engineering requirements for the installation of the turbines. It also includes an estimate for 'public realm' investment to minimise the impact on the surrounding environment and to maximise the local amenity value. Both of these expenditures are deemed important to ensure the project gains local community support and planning permission. These central capex estimates include a 20% cost contingency.

The estimated time required for construction of each tidal lagoon ranges from 3 to 4 years. Our assessment takes account of the profile of capex spends during the construction period. Tidal Lagoon Swansea Bay anticipates that the cost of development to be somewhat front-loaded. The profile is important for the LCOE calculation due to the mechanics of the net present value calculation which places greater weighting on costs incurred in the short term.

2.2.2 Changes in capex along project pipeline

The cost per unit of installed capacity (and hence per unit power output) is different for each project in the pipeline. Project costs are largely determined by the length of sea wall required to create a lagoon and the number of turbines appropriate for a particular site, while the electricity generation potential is a function of both the enclosed volume of water and the tidal range at that location.

The later projects in Tidal Lagoon Power's portfolio are expected to be larger (with a higher ratio of enclosed volume to perimeter wall) and/or at locations with a greater tidal range, and hence are likely to have cheaper capital costs than the Swansea Bay project. Unlike other low carbon technologies this is not due to an assumed technology learning profile but down to the geography of particular project sites. This implies that the cost reduction potential for tidal lagoon power is more certain than for other technologies such as offshore wind.

2.2.3 Operating costs and operating life

The total operating costs presented in Table 1 are shown as the annual cost requirement of maintaining the quoted power output for the lifetime of the asset. It includes operation and maintenance (O&M) costs, grid charges, and other costs such as insurance, rates, and seabed lease payments to The Crown Estate. It also includes a sinking fund which is paid into annually to cover the cost of any major refurbishment requirements over the lifetime and to cover the cost of decommissioning the infrastructure and restoring the environment to its natural state. A major benefit of tidal lagoons is the longevity of the asset, with an assumed operating life of 120 years.

2.2.4 Annual generation

The annual generation of each project is a function of its tidal flow profiles, the volume of water captured in a lagoon and its installed turbine capacity. The power output for each period of the day can be calculated with a high degree of accuracy due to the predictability of the tides. This means that although tidal lagoon power is an intermittent source of energy, with four energy producing periods per day around two tidal cycles, it is also highly predictable well in advance (unlike wind and solar generation).

The net annual electricity volumes assumed in this study are based on detailed modelling work commissioned by Tidal Lagoon Swansea Bay. They include allowances for maintenance, and mechanical and electrical losses.

2.2.5 Required rate of return

For simplicity, and comparability with other studies, we have assumed a required project (or ‘all equity’) rate of return (expressed on a pre-tax, real basis). Our assumption is based on the combined debt and equity requirements for project finance assumed in the Tidal Lagoon Swansea Bay financial model, which indicate that a discount rate of 6.5% (pre-tax, real) is appropriate. This assumption is comparable with the latest DECC publication which suggests a rate of 6.4%[4].

2.2.6 Uncertainty ranges

Our analysis recognises that there is a level of uncertainty around capital and operating costs and so we have modelled a range of costs (High, Low) shown in Table 2 around the central values in Table 1. This is important in determining the sensitivity of the results to uncertainty in input assumptions. For Lagoon 1, we have applied a 10% premium to the Central value for the High values, and a 20% saving to the Low values. The asymmetry recognises the conservative approach which Tidal Lagoon Swansea Bay has taken in its costing exercise. Due to the higher level of uncertainty of subsequent projects in the pipeline we have applied an even 20% shift in value for the High and Low estimates for Lagoon 2 and 3 (see Table 3).

Another major uncertainty in LCOE calculations is the required rate of return project investors will require. We have applied a 1% variance around our central estimate for our High and Low values.

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4 *Electricity Generation Costs*, DECC, December 2013

If the construction time required for a tidal lagoon overruns the LCOE is impacted due to the importance of costs incurred in the short term for any NPV calculation. We have therefore modelled a High value of one extra year of construction time.

Table 2 – Input assumption uncertainty ranges for Lagoon 1

Range	Low	High
Discount rate	-1%	1%
Capex	-20%	10%
Construction delay	No change	+1 year
Opex	-20%	10%

Table 3 – Input assumption uncertainty ranges for Lagoon 2 and 3

Range	Low	High
Discount rate	-1%	1%
Capex	-20%	20%
Construction delay	No change	+1 year
Opex	-20%	20%

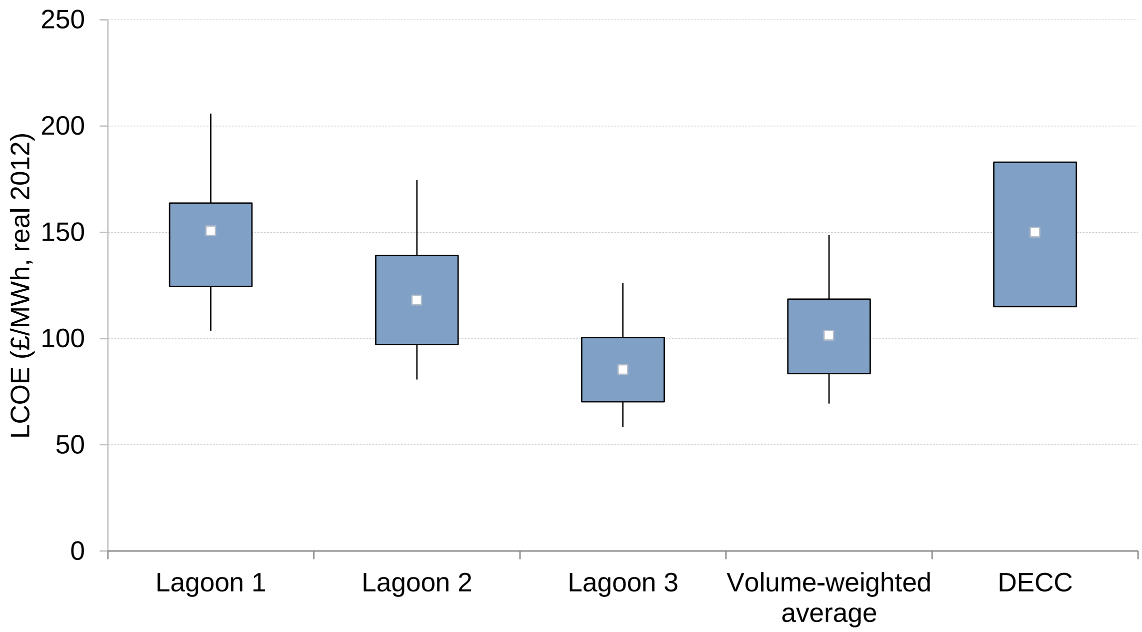
2.3 Levelised costs of tidal lagoon projects

Figure 2 shows our assessment of the LCOE for each of the three lagoon projects. The pipeline of lagoon projects shows levelised costs decreasing significantly, driven by the move to bigger sites with greater tidal range as discussed in Section 2.2.2. The central value for the LCOE of Lagoon 1 is approximately £150/MWh, while for Lagoons 2 and 3 this falls to around £120/MWh and £90/MWh respectively. The volume-weighted average central LCOE for the three lagoons is around £100/MWh, owing to the much larger size of the later projects compared to the first.

Figure 2 also shows DECC's assessment of the levelised cost of tidal range, taken from its December 2013 update of electricity generation costs. The DECC analysis assumes a construction cost range between £2,200/kW to £3,800/kW, operating cost of £38/kW/yr and a discount rate of 6.4% (pre-tax, real). It is not clear exactly what the source of these assumptions is, but they may derive from a 2010 study by Ernst & Young and Black & Veatch[5].

[5] *Costs of financial support for wave, tidal stream, and tidal range generation in the UK*, Ernst & Young and Black & Veatch, for DECC and the Scottish Government, October 2010. Note that this study appears to have considered tidal barrage schemes only.

Figure 2 – Levelised cost of energy for tidal lagoon



The central estimate is marked by white box, the bar range shows variance on capex assumption, and the line range adds uncertainty to opex, construction build time and discount rate.
Source: Pöyry analysis of Tidal Lagoon Swansea Bay input assumptions; Electricity Generation Costs (December 2013), DECC

One might ask why build Lagoon 1 if Lagoons 2 and 3 are cheaper. Tidal Lagoon Swansea Bay's response is that the total capital requirement for Lagoon 1 is significantly lower than for Lagoons 2 and 3 – around £1bn compared to £3-4bn. Although tidal range may be considered a mature technology, this is a first-of-kind project and reasonably it feels that investors will want to see the relatively smaller Swansea Bay project successfully developed before committing the much larger amounts of capital needed for the larger projects. In addition other stakeholders, such as policy makers, environmental groups and local communities, may prefer to see the smaller project developed first in order to gain confidence for the larger schemes.

The different costs for Lagoons 2 and 3 reflects the fact that even among larger and cheaper (compared to Lagoon 1) projects in the pipeline, there will be variation in project costs reflecting the unique site-specific characteristics of each project. Whilst ideally the cheapest projects should be developed first, this may not necessarily be possible for practical, regulatory and other reasons. TLP also notes strong socio-economic reasons underpinning the development of certain sites.

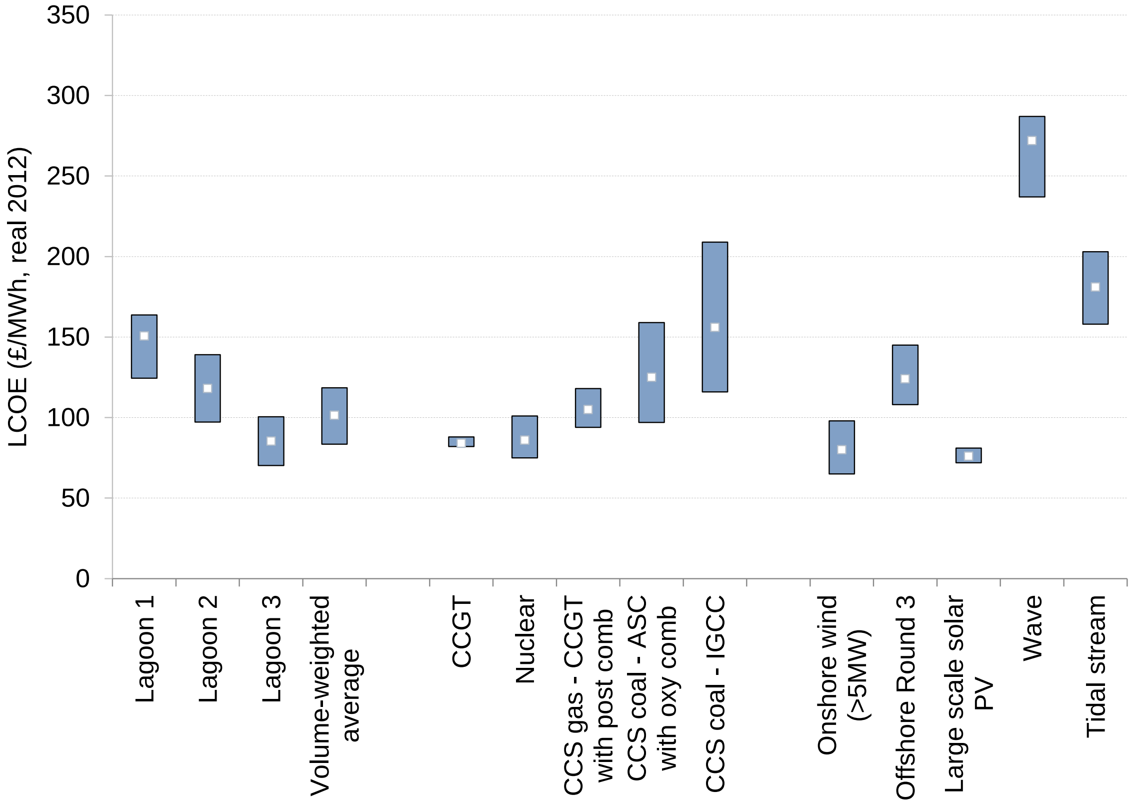
2.4 Comparison with other low-carbon technologies

In Figure 3 we compare the LCOE estimates we have calculated for Lagoons 1, 2, and 3 against other renewable and low-carbon technologies (including nuclear and carbon capture and storage (CCS)), plus combined cycle gas turbines (CCGT). The LCOE values for the other technologies have been taken from the latest DECC publication[6]. Each technology's LCOE has been calculated using a technology specific hurdle rate, and the highs and lows reflect DECC's high and low capital cost estimates.

6 *Electricity Generation Costs,* DECC, December 2013.

The cheapest lagoon project, Lagoon 3, has levelised costs broadly similar to onshore wind and large scale solar PV, considered to be among the more established (and cheapest) renewable energy technologies. Other technologies usually assumed to have a key role to play in decarbonising the grid in the period to 2030 are nuclear, CCS, and offshore wind. Figure 3 suggests that a portfolio of tidal lagoons could be a cheaper alternative than offshore wind and some forms of CCS, and could have costs broadly in the same range as onshore wind, nuclear and the cheaper forms of CCS. Wave and tidal stream energy also have significant potential in the UK, but tidal lagoons are substantially cheaper and can generate significantly more power than these less mature marine technologies in the short to medium term.

Figure 3 – LCOE estimates for projects commissioning in 2025, £/MWh (real 2012)



The central estimate is marked by white box, the bar range shows variance on capex assumption.
Costs for other technologies from DECC

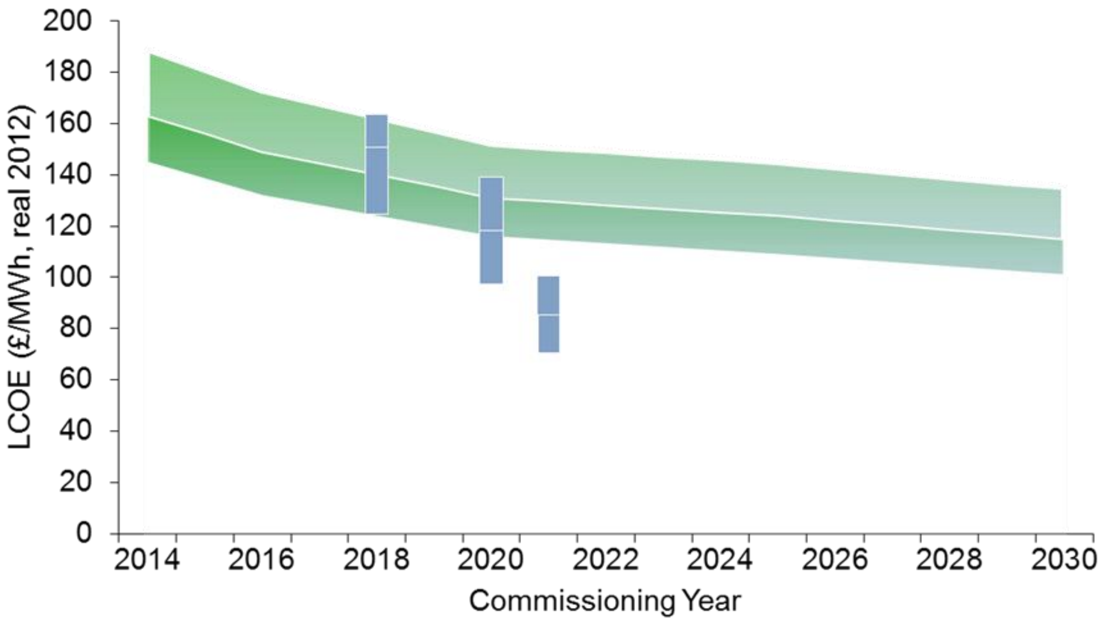
2.4.1 Comparison with offshore wind

Figure 4 compares the levelised costs of the tidal lagoon pipeline with estimates of the levelised cost for offshore wind. The assumptions for offshore wind have been taken from the latest DECC publication on electricity generation costs for a Round 3 project[7]. The central LCOE assumption for a Round 3 offshore wind farm in 2021 is £131/MWh.

7 *Electricity Generation Costs,* DECC, December 2013. Assumptions for offshore wind include an operating life of 22 years and a discount rate of around 10% (pre-tax real).

The declining cost of offshore wind over time relies on an assumption of continued technology innovation and learning over time, more developed and competitive supply chains, and improved financing costs[8]. The fall in cost for tidal lagoon projects does not account for any of these factors as in our analysis falling costs are wholly attributable to selection of site and economies of scale, although there is the potential that costs will fall as the domestic supply chain is developed.

Figure 4 – Comparison of tidal lagoon power LCOE with offshore wind



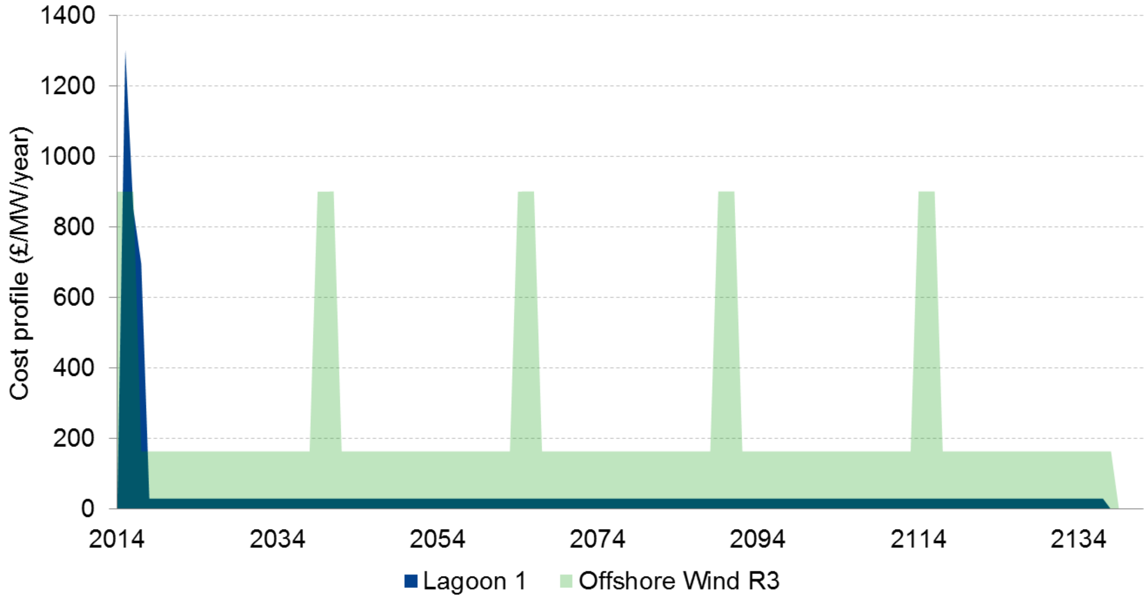
The green range shows LCOE estimates for offshore wind round 3 projects. The range bars show LCOE for our three lagoon projects with high and low capex estimates.
Source: Pöyry analysis of Tidal Lagoon Swansea Bay input assumptions; Electricity Generation Costs (December 2013), DECC

A single lagoon project lasts for around 120 years while offshore wind farms are generally assumed to have an operating life of 20-25 years. Hence around five generations of offshore wind farm are required to provide electricity for the duration of a single lagoon project. Figure 5 illustrates this point by charting the cost profile of Lagoon 1, including capital costs and lifetime operating costs, against five successive generations of offshore wind farms[9]. Whilst a tidal lagoon has over 100 years of low operating cost once constructed; whereas to provide offshore wind generation for an equivalent length of time requires five construction cycles as well as a higher level of ongoing operating costs. We estimate that adding the LCOE of the four subsequent projects, discounted back to today, would add around 10% in total to the LCOE of the first generation project. This estimation is not reflected in Figure 4.

8 *EMR Delivery Plan*, DECC, December 2013

9 Figure 5 does not consider the potential of technological development that could lower the cost of future wind farm installations.

Figure 5 – Lifetime cost profile comparison between tidal lagoon power and offshore wind



2.4.2 *Comparison with nuclear*

The later tidal lagoons have comparable costs to nuclear generation, as shown in Figure 6. As for offshore wind, the assumptions for nuclear have been taken from the latest DECC publication on electricity generation costs[10].

A single lagoon project lasts for twice the lifetime of a nuclear power plant delivering longer term cost benefit in terms of lower annual operational costs and avoided capital cost of reconstruction and decommissioning of nuclear waste. Figure 7 illustrates this point, although a simplification by not applying any discounting or technological development for future nuclear projects.

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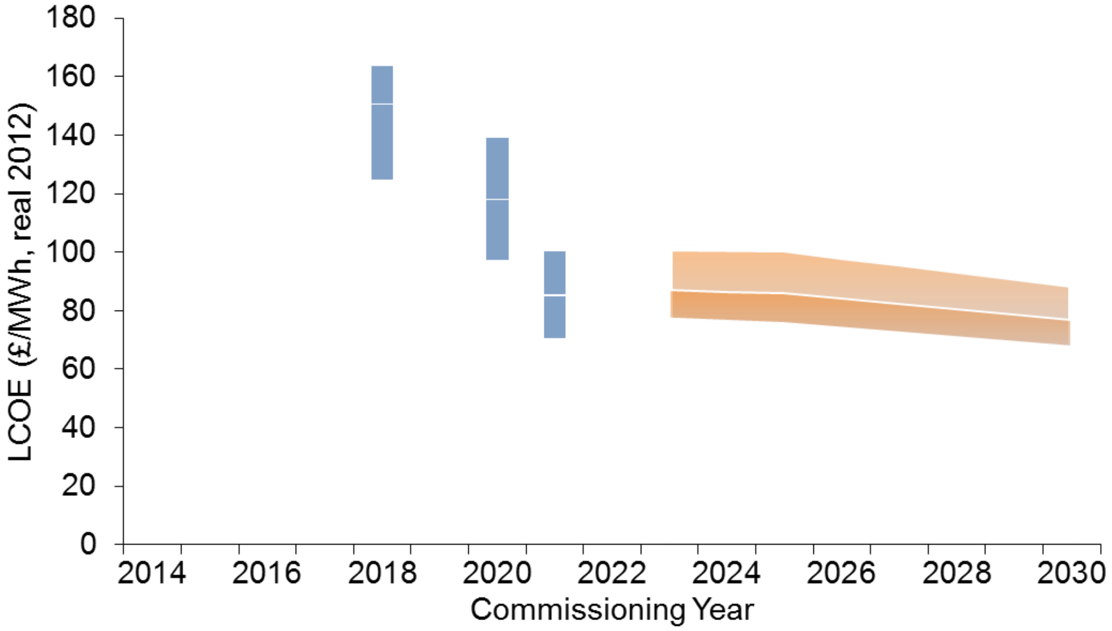
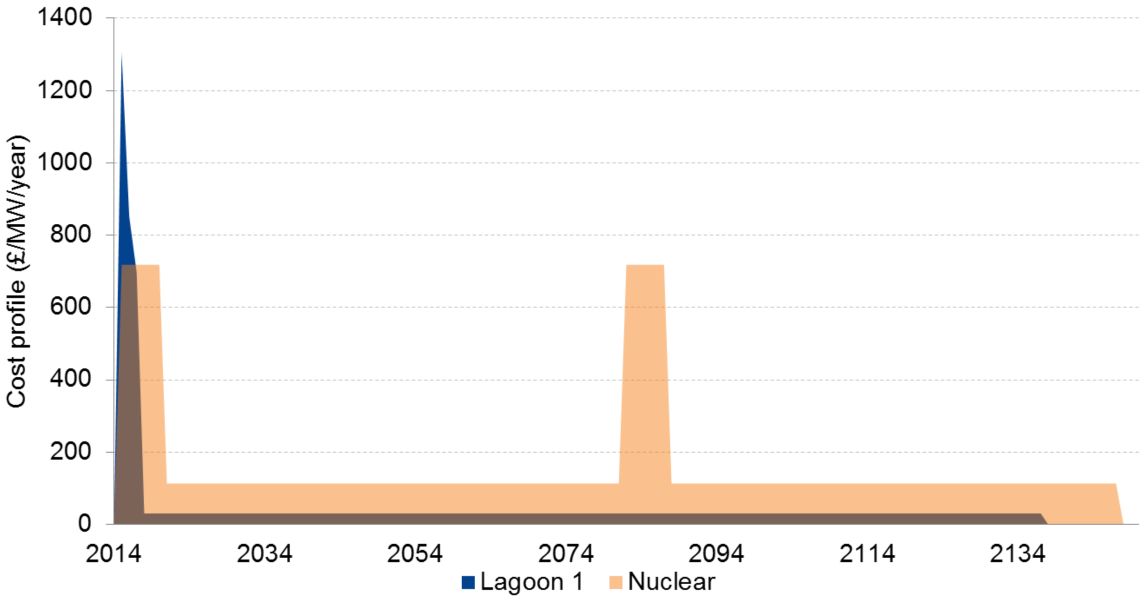
10 *Electricity Generation Costs*, DECC, December 2013. Assumptions for nuclear are based on a pressurised water reactor and include an operating life of 60 years and a discount rate of 9.5% (pre-tax real).

Figure 6 – Comparison of TLP LCOE with nuclear



The orange range shows LCOE estimates for nuclear projects, while the range bars show LCOE for the three lagoon projects with high and low capex estimates.
Source: Pöyry analysis of Tidal Lagoon Swansea Bay input assumptions; Electricity Generation Costs (December 2013), DECC

Figure 7 – Lifetime cost profile comparison between TLP and nuclear



Nuclear operating costs assumed to include a budget for any mid-life maintenance requirements and decommissioning costs through payments into a sinking fund.

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3. DETERMINING STRIKE PRICES

The UK Government is introducing a new support mechanism for low carbon generation. This involves entering into Feed-in Tariff Contracts for Difference (CfD FiTs) with eligible projects, whereby electricity market revenue is 'topped-up' to a pre-defined 'strike price'.

In this chapter we explain the methodology behind the strike price calculation, present our input assumptions for the calculation of the strike price, present our estimates of the required strike price for tidal lagoon projects, and finally draw comparison with other low carbon technologies.

3.1 The strike price calculation

The UK government CfD FiT support mechanism promises to deliver predictable revenue for lower carbon generation for a fixed length of time. When calculating the required strike price for a technology (or a specific project) the objective is to ensure that over the lifetime of the asset the power generating plant earns revenue to cover its LCOE and so this must be calculated first. There is then an additional step to translate the levelised cost into a required strike price, again based on a discounted cashflow calculation. The required strike price will be different from the levelised cost because:

- Levelised cost calculations are traditionally expressed as the cost of generation 'at the station gate'. However the generator is likely to incur additional costs in selling its output into the wholesale electricity market, such that on average it will realise less than the reported wholesale price. This may arise from various sources – for example any 'basis risk' between the reference price used for CfD settlement and the price actually achieve in the market, the cost to generators of transmission losses, and any 'PPA discounts' associated with securing a route to market. These additional costs must be added to the strike price calculation to ensure that the generator earns its required return.

- The levelised cost is calculated over the expected operating life of the asset, whereas CfD support will be for a specified period which may be shorter than this. We then assume the asset earns wholesale electricity market revenues for the remainder of its life. If electricity prices at this back-end period are lower than the levelised cost, then the required strike price for the support period must be higher than the levelised cost to compensate for this.

3.2 Input assumptions

3.2.1 Route to market costs

PPA discount

In deriving its strike prices DECC has assumed 7% PPA discount for non-intermittent renewables[11], meaning that on average a baseload renewable generator is assumed to earn only 93% of the published wholesale electricity price. The difference is accounted for by the need to compensate power purchasers for providing a route to market and for various risks they face in the market such as imbalance risk (admittedly small for a tidal lagoon project). Even if a generator trades directly in the wholesale market, rather than

11 *EMR Delivery Plan*, DECC, December 2013

via long term power purchase agreement, there will still be a cost associated with trading and managing trading risks.

DECC assumes offshore wind can achieve a lower cost of accessing a route to market and applies a 5% PPA discount. We are unclear as to the rationale for this, as we believe the volumes risks associated with an offshore wind farm will be greater than for a baseload, controllable, generator, as there will be a relatively high trading cost associated with managing within day variations against expected output. For this reason we believe the PPA discount applied to a tidal lagoon should be no greater (and arguably smaller) than that for offshore wind, and so in estimating tidal lagoon strike prices we assume 5% also.

Transmission losses and BSUoS

Under the Balancing and Settlement Code, a 'Transmission Loss Multiplier' ("TLM") is applied to generator meter readings to account for transmission losses between the meter and the notional trading point for wholesale electricity. This varies half hourly, but a reasonable assumption for the average value would be 0.992. This means that for every 100MWh generated, the generator is only credited with 99.2MWh. Similarly, the proposal is that CfD payments will be made on loss-adjusted (i.e. scaled down) volumes.

Tidal lagoon power will be liable for Balancing Services Use of System (BSUoS) charges under the Connection and Use of System Code. These are payable to the System Operator (NGC) and are designed to pay for the cost of system operation (balancing services, ancillary services, etc.). These costs are currently allocated equally between generation and demand. A recent proposal to remove generator BSUoS and recover 100% from demand has been over-ruled by Ofgem. Hence we assume an ongoing BSUoS charge of £1.50/MWh.

3.2.2 Duration of CfD support

Given the very long life of a tidal lagoon project, we have assumed a 35-year support period. DECC has set recent precedent for long term contracts with the announcement of the 35-year Hinkley Point strike price contract. One of the key arguments for awarding nuclear a long term contract was the fact that its lifetime is 60 years and so will contribute low cost electricity into the wholesale market once the contract has expired. The same argument is appropriate for tidal lagoon power except its lifetime is twice as long at 120 years. It may be appropriate to suggest a longer CfD duration than the 35 years assumed in this analysis.

3.2.3 Wholesale electricity price

This is required in the strike price calculation to model revenues once CfD support has ended. DECC typically assumes investors have only five year's foresight of electricity prices, and assume constant prices (in real terms) beyond then. We have replicated this philosophy here and assumed a wholesale electricity price of £65/MWh for the lifetime of the asset. This assumption really only has relevance after the expiry of the CfD. For a 35-year CfD term changes to this assumption have a trivial impact on discount rate and required strike price.

3.2.4 Climate Change Levy Exemption Certificates (LECs)

As a renewable generator we believe that a tidal lagoon should qualify for Renewable LECs. The face value of a LEC is the level of Climate Change Levy (CCL) – currently £5.24/MWh. However the PPA off-taker will typically pay 60-90% of this.

Note however that we view LECs are a relatively risky revenue stream (compared to CfD payments for example), with a high level of regulatory risk. In estimating strike prices we have assumed a tidal project earns LECs only until 2023 and sells these for 75% of the face value of CCL.

3.3 Strike prices of tidal lagoon projects

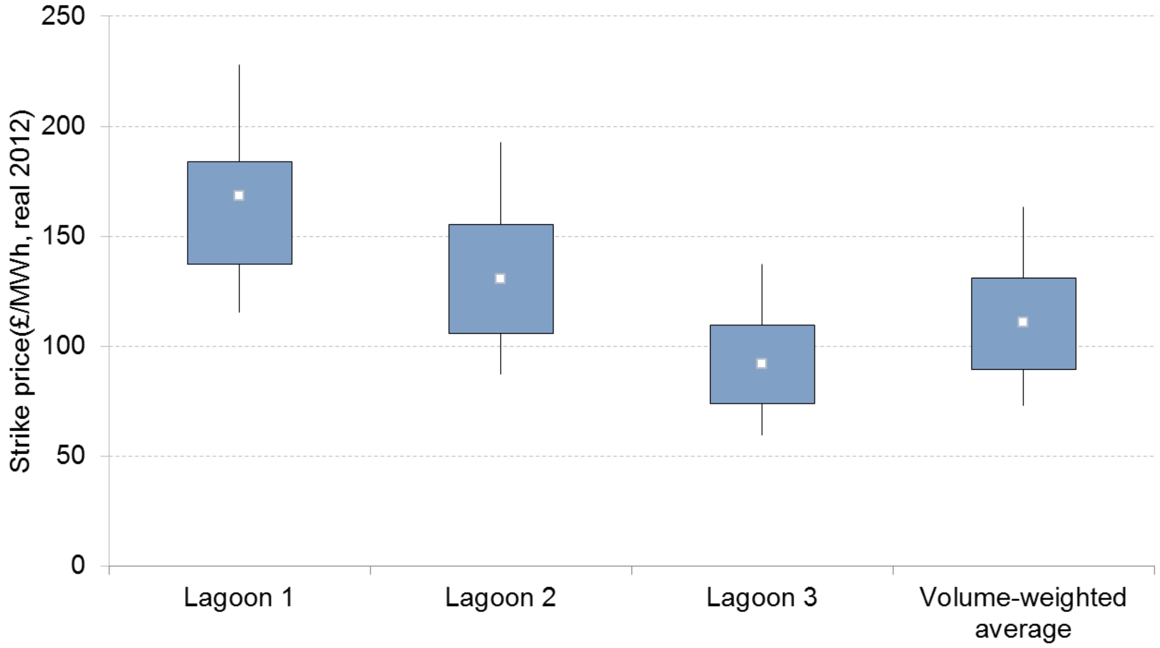
Figure 8 shows our assessment of the range of required strike prices for each of the three lagoon projects. The pipeline of lagoon projects shows the required strike prices decreasing significantly, in line with LCOE as discussed in Section 2.3, and driven by the move to bigger sites with greater tidal range as discussed in Section 2.2.2. The central value for the strike price of Lagoon 1 is around £168/MWh, while for Lagoons 2 and 3 this falls to around £130/MWh and £92/MWh respectively. The volume-weighted average central strike price for the three lagoons is around £111/MWh, owing to the much larger size of the later projects compared to the first.

The CfD strike price for offshore wind announced in the EMR Delivery Plan is £155/MWh for projects commissioning in 2014/15, decreasing to £140/MWh by 2018/19. Whilst Lagoon 1 requires a strike price above offshore wind, Lagoon 2 is competitive with offshore wind and Lagoon 3 is significantly cheaper. The reality is that each potential tidal lagoon site in the project pipeline will require a different strike price in order that investors can reach a final investment decision – some may require a higher price and some will require a lower price compared with offshore wind. However the volume-weighted average strike price of £111/MWh for the three projects which we examine is considerably lower than the strike prices for offshore wind.

These results are based on the key assumptions of a 35 year CfD contract followed by full commercial exposure to the wholesale electricity price (and also account for route to market costs and LEC revenue as described in Section 3.2). The 35-year length of CfD contract is justified on the basis that the project lifetime is twice the length of nuclear, which negotiated a 35 year deal. All other renewable technologies are being offered a 15-year CfD. If we apply this contract length the central value for the strike price of Lagoon 1 is approximately £214/MWh, while for Lagoons 2 and 3 this falls to around £159/MWh and £102/MWh respectively. This increases the volume-weighted average strike price to £130/MWh which is still competitive with offshore wind.

The range of strike prices in Figure 8 reflects the range of LCOE values calculated. The bar range shows variance on capex and the line range adds in the uncertainty for opex, construction time and discount rate. For further detail on the uncertainty ranges see Section 2.2.6. We examine the impact of changes in individual input assumptions in more detail below in our sensitivity analysis in Section 3.4.

Figure 8 – Required strike price for tidal lagoon projects



The central estimate is marked by white box, the bar range shows variance on capex assumption, and the line range adds uncertainty to opex, construction build time and discount rate.

3.4 Strike price sensitivity analysis

The main drivers of uncertainty in our strike price calculation for tidal lagoon power include construction costs, construction delays and the risk premium required by investors. Figure 9 shows the sensitivity for Lagoon 1. The asymmetric range on capex and opex recognises the conservative approach Tidal Lagoon Power Swansea Bay took to project costing.

Figure 9 – Lagoon 1 sensitivity of strike price to uncertainty in input assumptions

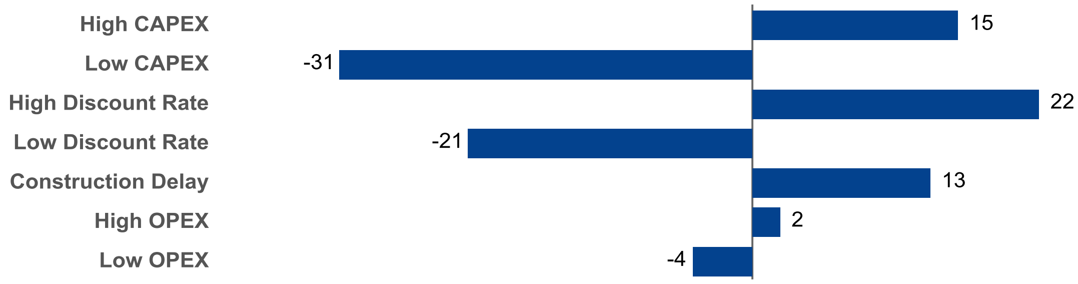


Figure 10 and Figure 11 show the sensitivity analysis on Lagoon 2 and Lagoon 3 respectively.

Figure 10 – Lagoon 2 sensitivity of strike price to uncertainty in input assumptions

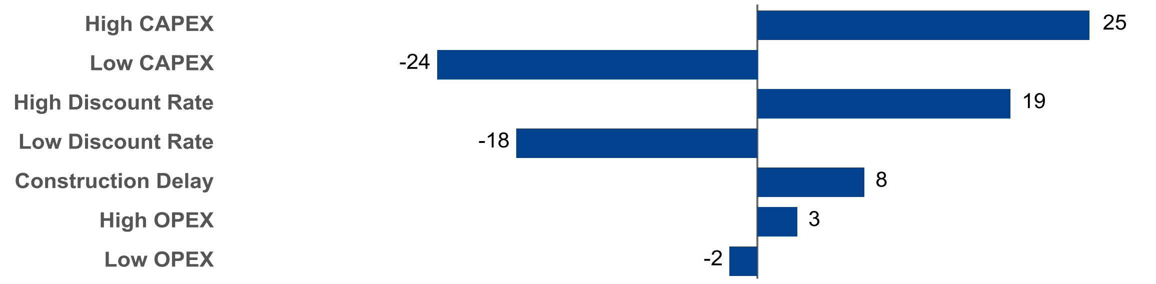
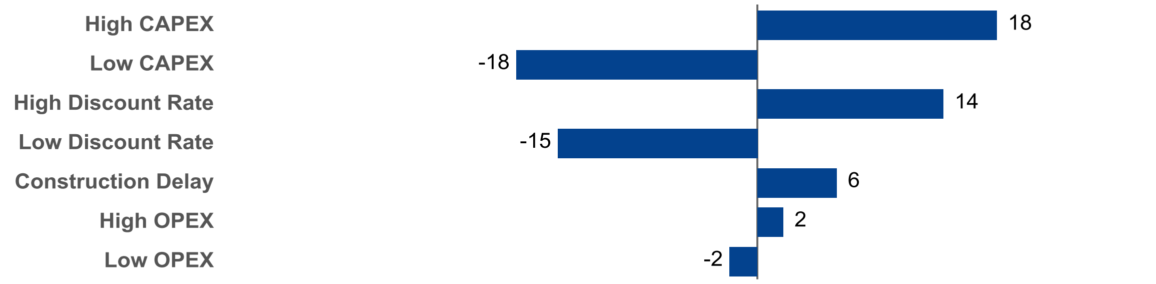


Figure 11 – Lagoon 3 sensitivity of strike price to uncertainty in input assumptions

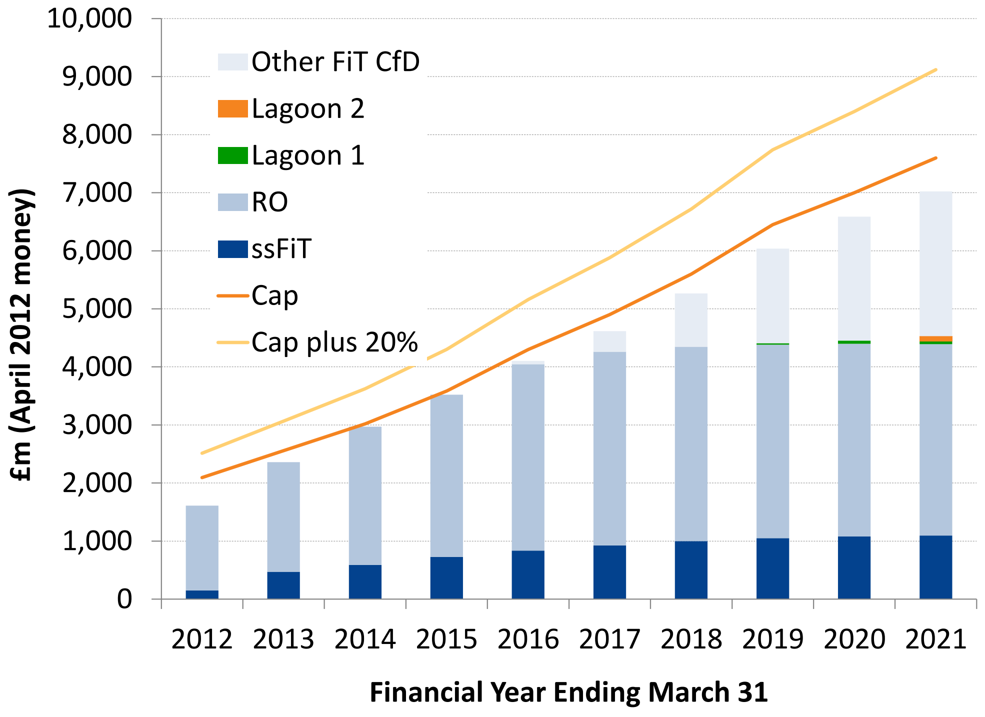


3.5 LCF budget

The Levy Control Framework (LCF) is essentially a cap on financial support for renewable and low carbon technologies imposed on DECC by the Treasury. The level of the cap has been defined with annual budgets published up to 2020/21. The budget for 2021 is £7.6bn (in April 2012 money). Around half of this amount has already been committed to generators registered under the existing small scale FiT scheme and the Renewables Obligation scheme, meaning that all future schemes must compete for funding from the remainder.

Supporting tidal lagoon power has minimal impact on the LCF budget to 2020/21, as shown in Figure 12. The thin green bar in Figure 12 shows the total support cost for Lagoon 1. Based on our analysis, the support cost for Lagoon 1 is £52m per year assuming a strike price of £168/MWh. The incremental cost compared to an equivalent volume of offshore wind generation is approximately one quarter of this or approximately £13m per year. The estimated support cost for Lagoon 2 is £169m per year, assuming a strike price of £130/MWh for Lagoon 2 (thin orange bar in Figure 12). This is around £25m/yr cheaper than an equivalent volume of offshore wind. (Note however that this analysis is based on the annual support costs and does not take the duration of support into account.)

Figure 12 – Levy control framework budget to 2020/21 (£m, April 2012 money)



Source: Pöyry analysis with DECC projections from 'The Levy Control Framework', NAO, November 2013

Figure 13 – Present value support cost comparison between tidal lagoon power and offshore wind (£/MWh, real 2012 money)

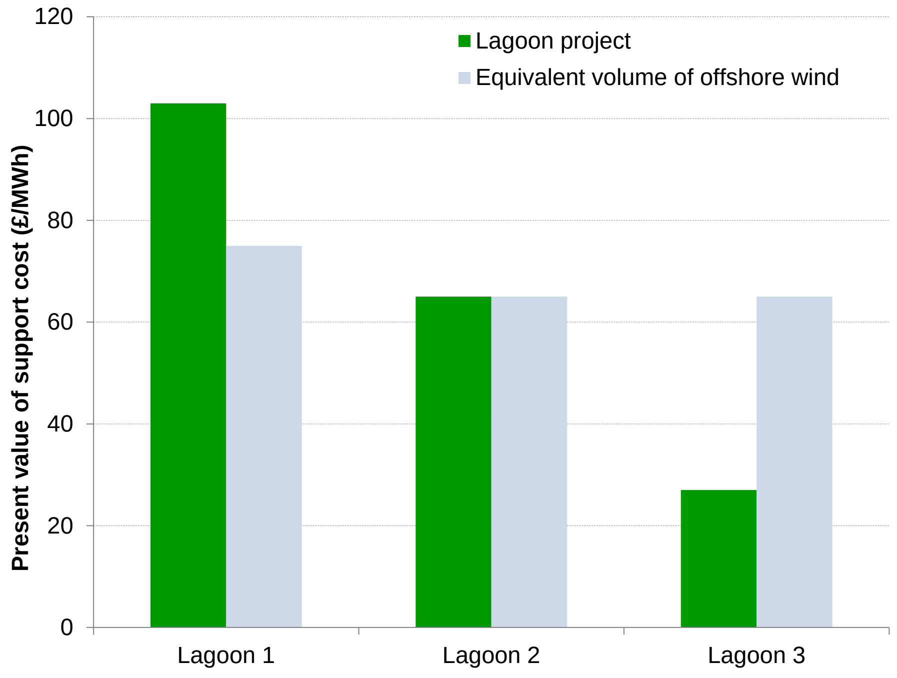


Figure 13 shows the present value of total support payments for each lagoon in terms of energy output, based on an assumed long-term power price of £65/MWh and using a 3.5% real social discount rate. For Lagoon 1, we compare against an offshore wind project commissioning in 2018 with a strike price of £140/MWh. Strike prices have not been announced for offshore wind farms commissioning in the early 2020s, when Lagoons 2 and 3 are assumed to come on line – we have assumed £130/MWh to reflect the expectation of continued cost reductions in offshore wind. This comparison takes account of the longer CfD duration (35 years) for tidal lagoons compared to offshore wind (15 years).

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4. OTHER BENEFITS OF TIDAL LAGOON POWER

In the previous chapter we have shown that tidal lagoons have the potential to deliver renewable energy at significantly lower support levels than offshore wind, which is seen as the 'marginal' renewable electricity technology for the UK. In this chapter we discuss qualitatively some of the other benefits of tidal lagoons compared to offshore wind. These are generally harder to quantify, and such quantification is beyond the scope of this report, but nevertheless they demonstrate that tidal lagoons offer a number of wider electricity system benefits.

4.1 Tidal lagoon power is predictable

The timing and amplitude of tides can be determined years ahead of time, and so the output of a tidal lagoon generator can be considered predictable. The only uncertainty arises from uncertainty about availability of turbines (i.e. forced outages), but even then the multi-turbine configuration of a tidal lagoon power station means that a problem with one turbine generator will result in a loss of only part of the output.

This contrasts with offshore wind, where there is inherent uncertainty in wind forecasts. This results in a requirement to have back-up capacity on the system ready to come on line at relatively short notice should the output of a wind farm be different than expected. It is anticipated that this will be provided by gas-fired capacity – either open-cycle gas turbines (OCGTs) or closed-cycle gas turbines (CCGTs).

The new Capacity Market being introduced by the Government from 2018 is intended to incentivise the provision of such back-up capacity by paying a capacity price to power stations which are available at times of system stress[12]. The first capacity auctions are due to take place towards the end of 2014 so capacity prices are not yet known. However the Government has suggested an upper limit to the auction price based on its assessment of the cost of new entrant OCGTs (since OCGTs are anticipated to be the marginal providers of new back-up capacity)[13]. The Government's view is that the cost of new OCGT capacity is £47/kW/yr (in 2013 money), and that the net "cost of new entry" ("CONE") after accounting for other electricity market revenues is £29/kW/yr[14].

We estimate that the Swansea Bay Tidal Lagoon (Lagoon 1) is roughly equivalent to a 140MW offshore wind farm in terms of energy output. Based on this net-CONE assumption, the cost of an equivalent amount of back-up capacity would be around £4m/yr.

Of course a tidal lagoon does not generate electricity 'baseload', and other capacity will be required to provide electricity when the tide is turning. However the requirement for this will be known in advance and so its provision can be planned and optimised in advance. Because high and low tides occur at different times around the coastline, then a portfolio of appropriately-sited tidal lagoons would have a much smoother generation profile than a single lagoon, thus reducing the requirement for generation from other sources. This

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12 Generators receiving support through the Renewables Obligation or CfD FiTs will not be eligible for capacity payments.

13 *Electricity Market Reform: Consultation on Proposals for Implementation*, DECC, October 2013 (see Section 4.2.13)

14 The upper limit on the Capacity Market auction price may then be set as a function of the net CONE value – perhaps 150% – to allow for uncertainty in this value.

portfolio effect is less applicable for offshore wind, where a high pressure system can envelope the whole country.

4.2 Tidal lagoon power may offer some despatch flexibility

We are advised by Tidal Lagoon Power that there is some scope to alter the generation profile of a tidal lagoon by holding back water for a limited period. Although this scope is limited by the need to empty or fill the lagoon in time for the next cycle, it may offer some opportunity to offer ancillary services to the grid or to shift generation to more valuable periods.

4.3 Tidal lagoons are long-life assets

In our analysis in Chapter 2 we have assumed an operating life of around 120 years for tidal lagoons (and included costs provisions for renewing equipment such as turbines during this period). This compares to offshore wind, where the operating life is generally assumed to be in the range 20-25 years. This very long asset life means a tidal lagoon will be generating low cost renewable electricity long after CfD expiry, and the consumer will continue to benefit from this through low wholesale electricity prices.

The levelised cost calculation presented in Chapter 2 takes operating life into account, but the value of the later years of a long-life asset is discounted heavily. In determining levelised costs we have used technology-specific discounts rates reflective of the perceived risk of investing in that technology. This approach is appropriate for private sector investment decisions, but does not necessarily reflect the benefit to society of a very long-life asset.

In many areas of policy-making, the Government uses a social discount rate of 3.5% to evaluate the future costs and benefits to the public of policy decisions[15]. Applying a discount rate of 3.5% to Lagoon 1 yields a LCOE of around £90/MWh, with the equivalent numbers for an offshore wind project also being around £90/MWh. In other words, even Lagoon 1 is competitive with offshore wind when valued using a social discount rate. At this discount rate the estimated LCOE values for Lagoons 2 and 3 are around £70/MWh and £50/MWh, compared to over £80/MWh for gas CCGT[16] (usually considered to be the cheapest technology).

Another potential criticism of our levelised costs comparison in Chapter 2 is that it should compare one tidal lagoon project with five sequential offshore wind projects rather than a single offshore wind project, since a tidal lagoon lasts for around five times as a long as an offshore wind project, albeit that the successor offshore projects should be discounted back to today and so will have lower and lower value in today's terms. As discussed in Section 2.4, we estimate that adding the LCOE of the four subsequent projects, discounted back to today, would add around 10% in total to the LCOE of the first generation offshore wind project.

15 In fact the Treasury's *Green Book* suggests that even lower discount rates might be appropriate for the very long term: 3.0% for 30-75 years and 2.5% for 75-125 years.

16 Based on DECC gas and carbon price assumptions.

5. CONCLUDING REMARKS

The Climate Change Act sets a legally binding target of reducing UK greenhouse gas emissions by 80% (compared to 1990 levels) by 2050. This implies a significant decarbonisation of the electricity generation sector by 2030, with The Committee on Climate Change recommending a target of 50gCO_2/kWh. This is a very challenging ambition, and achieving it will require significant deployment of a range of low-carbon generation technologies such as onshore and offshore wind, nuclear, and carbon capture and storage. At this stage there is a high level of uncertainty about how quickly some of these technologies can be deployed.

In addition, the Government is rightly concerned that the cost of deploying low carbon technologies should be kept to a minimum. The longer term ambition is that the cost of low carbon technologies should be competitive with fossil fuel alternatives (assuming an appropriate carbon price signal). Where Government supports more expensive technologies such as offshore wind, this is on the expectation that its costs will decline over time as the technology matures.

Tidal lagoon power has the potential to play a significant role in this low-carbon future, with the Crown Estate estimating a tidal lagoon resource potential in the region of 25TWh per year. Although Tidal Lagoon Power's first project, Swansea Bay, is slightly more expensive than offshore wind, later projects are likely to be cheaper than offshore wind and in some cases competitive with nuclear. This cost reduction arises primarily from moving to larger sites with greater tidal range rather than any assumption of technology learning. The incremental support cost of the first project (compared to the alternative of offshore wind) appears justified if it also buys the potential option to develop larger and cheaper projects soon after.

Tidal lagoon power projects are long-life assets which can contribute low-carbon electricity for many years beyond the period of financial support through a CfD. Tidal lagoon power would add to the diversity of future low-carbon generation and, because it has the potential to deliver renewable energy at scale can help to reduce the deployment uncertainty associated with all low carbon technologies. Our analysis of Tidal Lagoon Power's project pipeline has shown that large-scale tidal lagoon power has the potential to be a relatively cost-effective low-carbon technology.

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