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ENFAIT
ENABLING FUTURE ARRAYS IN TIDAL

LCOE & Financial Models

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Contents

1 The Project

1.1 Introduction

A Funding Grant was awarded from the European Union's Horizon 2020 research and innovation programme in January 2017 to demonstrate a grid-connected tidal energy array at a real-world tidal energy site, propelling tidal energy towards competing on a commercial basis with alternative renewable sources of energy generation – Enabling Future Arrays in Tidal (EnFAIT). This was in response to the call *LCE-15-2016: Scaling up in the ocean energy sector to arrays* to generate significant learning through demonstration of cost-effective tidal arrays.

This document is produced to outline a lifetime cost of energy model for tidal arrays, supported by a detailed tidal array project financial model. It is to be submitted to satisfy deliverable D3.9 of the EnFAIT project and to be also made available for public dissemination.

1.2 Overview

Within the marine energy sector tidal stream has advanced its technology offering to a point where it is on the cusp of competing with high cost dispatchable generation (see Section 3). To assess the addressable market for tidal stream requires power generation financial modelling, incorporating a series forecasted technological enhancements based around a series of assumptions which attempt to present a potential pathway towards commercialisation. Our approach has involved an investigation into the Levelised Cost of Energy (LCOE) for tidal stream technologies. This report draws upon our exposure to the tidal stream sector and including any public documentation where possible.

Overall there are currently circa 18MW of tidal stream devices installed globally which are largely classified as first of a kind pre-commercial deployments. The classification of a pre-commercial deployment involves funding from a combination of private money, grant funding and a regulatory support mechanism (e.g. green certificate/feed-in tariff or contract for difference (CfD)) pricing mechanism). We envisage the tidal stream sector will require further phases of pre-commercial deployment and testing before it is able to reach financial close through a combination of private funding and a government sponsored regulatory mechanism. By removing the need for grant funding, subject to governments providing a regulatory support mechanism, the sector can play an important part of the energy mix particularly with the increased level of intermittent renewables burdening system balancing costs.

In this report we provide a likely pathway for the tidal stream sector to reach a point where it is a commercially viable option within the power generation mix and set out a structure for a tidal array project financial model.

2 Current Cost of Tidal Stream

In the last two years 15MW's of tidal stream have been installed, mainly in European waters with a limited exposure to Asia and North America. The LCOE for pre-commercial deployments to date convey a wide range of capex and opex per-MW (mega-watt) installed, largely a result of the following reasons during the design, build and operate phase:

- Variation in turbine/array capacity – and therefore economies of scale effect.
- Resource deployment disparity.
- High cost of heavily instrumented devices for monitoring purposes and learning.
- One off component and material defects.
- Unexpected/planned remediation and repair activities.
- Lack of supply chain knowledge and limited competition in bidding during the turbine build phase.
- Turbine fabricator sharing build learning with developer/turbine designer leading to a lengthening manufacturing timescale and therefore increasing costs.
- Under resourced management teams leading to sub-optimal contracting strategy.
- Lack of experience in large scale fabrication and complex build programming.
- Under estimation of time and labour from engineering scope, the number of components and the complex prototype one-off design verification requirements.

The key challenge in predicting first of kind commercial tidal arrays (combination of private money and a government support mechanism – e.g. feed-in tariff or CfD) is the acquisition of meaningful data. In Table 1 we provide evidence of a small sample of data from pre-commercial projects ranging from kW to multi-MW scale. From these pre-commercial demonstrator projects we expect the LCOE to be more than circa €345/MWh ($393/MWh). The kW scale turbines demonstrate the highest costs mainly due to dis-economies of scale, while multi-MW benefit from the scale effect. The LCOE data provided below is further supported by projects relying on the use of grants to reach financial close combined with accessing the previous UK government support mechanism of 5 renewable obligation certificates (ROC's) per MWh produced.

Table 1: Pre-Commercial Demonstrator Tidal LCOE

Tidal Turbine Rating	Capex Range/MW	Total Annual Opex	LCOE/MWh
1.5 – 2.0MW	€6.0mln - €8.7mln	€262k - €456k	€345 - €520
< 1.0MW	€10.0mln - €12.2mln	€200k - €787k	€472 - €784

Due to the level of unplanned events taking place during the design, build, implementation and operation phases we have taken these known high cost events[1] and adjusted them to achieve a credible base line for the first of a kind commercial array. We provide details of the LCOE pathway in Section 3 of this report.

2.1 Comparative Power Generation LCOE

To understand the relative commercial strength of tidal stream's cost of energy we need to compare this against competing generating assets dispatching power to the grid.

The cost of energy supply is core to the short and long-term viability of any energy technology. For the tidal stream sector economic cost reduction pressure is imperative for its growth prospects. All new technologies learn with experience and production volume and in step with this phenomenon we expect tidal stream to be no different. Wood believes it is critical that tidal steam suppliers and developers can demonstrate a clear pathway to cost convergence with dispatchable power generation.

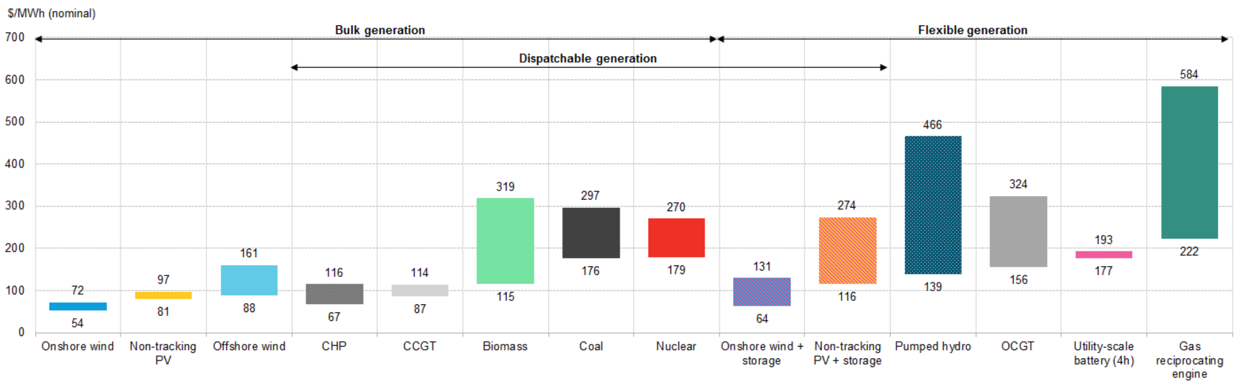

Figure 1: UK Current LCOE Averages

In Figure 1, we provide evidence of the current levelised cost of electricity supply from a UK data set[2]which is a world leader in tidal stream development and resource assessment. Although wind and solar costs have largely undercut traditional base load thermal power capacity, its intermittency has placed a greater financial and technical burden in the operation of grid infrastructure. Increased intermittency has also resulted in greater electricity pricing volatility combined with lower thermal based load utilisation. Consequently, higher marginal cost fossil fuel power plants require a subsidy to remain operational. The predictable generation profile of the tidal stream energy is ideally suited to displace and harmonise with thermal generation in step with permanently reducing climate change related greenhouse gas emissions.

We recognise that tidal stream cannot be deemed to be 'dispatchable' generation (unless married with battery storage). However, it is predictable allowing its generating capacity to operate in concert with incumbent capacity. Therefore, its contribution to the grid will be more valuable than intermittent power

[1] Cost items include: fabrication/product delays due to design change/miscalculation, poor contract management strategy, overly specified instrumentation installed for measurement and analysis purposes and repair and retrieval costs due to technical faults which have been subsequently learned and reduced availability.

[2] The LCOE data input represents a range of costs and capacity factors. Battery storage systems (co-located and stand-alone) retain a capacity of 4 hours duration. In the case of solar and wind plus battery systems, the range is a combination of capacity factors and size of battery relative to the power generating asset (25% to 100% of total installed capacity). For stand-alone battery systems the LCOE range represents a diversity of financing costs and charging prices. In countries where a carbon market operates (e.g. UK and China) the LCOE includes carbon costs. All LCOE calculation and unsubsidised. Source data BNEF.

from wind and solar. That said, to reach price convergence in the market today with renewable based generation (on/offshore wind and solar) would be in the region of €47 to €141/MWh ($54 to $161/MWh). By comparison, the current cost of tidal energy from pre-commercial deployments is in the region of €345/MWh to €784/MWh ($393/MWh to $894/MWh)

2.1.1 Wholesale Power Outlook

Despite ongoing efficiency and cost reduction in wind and solar we expect that wholesale power prices are likely to experience net price inflation over the short to medium term (circa 20 years) to meet the commitments contained within the recently signed Paris Agreement[3]. Therefore, we do not share the view that merchant power prices will be strongly correlated with intermittent based wind and solar LCOE reduction. Furthermore, due to regulatory mechanisms the cost of decarbonising the electricity generation market is not currently reflected in merchant power price. The decarbonisation cost is paid through a levy on the consumer, leaving the wholesale power price largely insulated from market forces due to the regulatory mechanism.

To date, decarbonisation has largely taken place through the retirement of coal burning power stations which in turn has reduced surplus generation to cover demand peaks. Consequently, we have witnessed greater electricity pricing volatility which has been exaggerated by low marginal cost renewable power during peak resource periods in wind and solar. However, the cost associated with full decarbonisation of all energy systems including; mass heat and transport systems, land use (clearing of forests/carbon sinks and use of natural gas to produce fertiliser/nitrogen) in addition to negative emissions, requires a substantial replacement of fossil fuel based thermal processes. To mobilise the required capital to build sufficient capacity while stabilising the grid will involve substantial change to supply chains, natural resource constraints[4] in addition to the adaption and insurance cost associated with a warming world contained within the emissions pathways to meet 1.5 to 2.0-degree warming scenarios. At its most ambitious, the Paris Agreement implies a transition within the global energy system such that greenhouse gas emissions fall rapidly from 40 billion tonnes per annum, to net-zero by the middle of the century.

Long term electricity price forecasts are subjected to a range of uncertainties. However, a common theme and greatest price influencer is the cost associated to meet carbon budgets ascribed to the Paris Agreement. The electrification and decarbonisation of all energy systems (mass transport, agriculture, industrial processes) will entail a greater share of renewable energy technologies combined with storage to enable carbon stock (held in the oceans and soils rather than atmosphere) to be replenished. Failure to mitigate carbon emissions will result in carbon price inflation which inevitably results in higher pass through costs for carbon-based products and services (e.g. gas fired power stations, steel, cement, food production, transport, global trade etc). This theme will stimulate further renewable energy development; however, it will allow for increased profitability from renewable energy generators (versus high carbon intensity products and services) until such time emissions reductions are met in compliance with the global Paris Agreement. The transition towards a low carbon economy will require multiple decades to implement and as such renewable energy projects will benefit from legacy inflationary carbon-based processes. Not until greenhouse gas emissions are on a predictable pathway towards its natural equilibrium can we expect to witness a deflationary world for wholesale electricity prices.

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[3] Paris Agreement terms and obligations - https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[4] Raw materials required for renewable energy mass scale deployment including storage (e.g. copper, lithium brine, iron ore, cobalt, nickel, gadolinium, platinum, neodymium, dysprosium etc)

It is common to all countries with a high renewable energy market share to witness expensive power costs at the point of use. Historically, this is the result of regulatory systems compensating renewable energy systems through a tax at the point of consumption rather than through the wholesale power price. It is for this reason that we see low wholesale prices (due to low marginal cost of renewable versus fossil thermal) in the likes of Germany and Denmark with a correspondingly high retail price for power. Although significant cost reduction has taken place in renewable power systems the cost associated with additional stand-by capacity at lower annual utilisation through nuclear and thermal power means that the overall cost associated with power delivery is commensurately higher.

In summary, Wood expect the cost of energy supply will outpace the purchasing power of money in the future. In our view, the long-term outlook for electricity pricing is inflationary and this suggests the cost associated with carbon free dispatchable generation will be a beneficiary and could accelerate the rate of tidal stream deployment as carbon pricing crowds out fossil based thermal plant.

3 Cost Reduction Pathway

In the capital goods sector, learning curves are typically used to predict longer-term cost reductions. For each doubling of the deployed capacity, a certain percentage cost reduction is attained. Similar renewable energy technologies have historically attained learning rates in the order of 10%-30%. Wind technology, for example, which is the most closely related to tidal energy, has demonstrated learning rates in the region of 16%. Cumulative cost reductions are tied to a wide range of influences that can drive cost down, including manufacturing scale, operational efficiencies, improved reliability and availability, and fundamental design changes. Our confidence in cost reduction can be summarised by the following:

- Economies of volume - substantial cost reduction with standardisation
- Economies of scale - both device rating and array capacities
- Learning rates from repeat manufacturing and deployment
- Improved reliability, efficiency and availability
- Tidal stream is modular and scalable and so can be flexibly sized to the available resource and environmental constraints;
- The energy density of tidal flows is much greater than that of other forms of renewable energy such as wind or solar energy. This suggests that ultimately a lower cost of energy may be possible from tidal energy extraction and a smaller geographical footprint.
- Fabricated steel content is less than offshore wind installations, per MW, and the key drivetrain components are essentially the same as used in wind turbines.
- Potential opex advantage from being much closer to shore (versus offshore wind).

The above key drivers for tidal stream means there is no reason why the LCOE for tidal energy should not be very close, on a like-for-like basis to that of other renewable based generation (see Figure 2), even at very early stages of deploying 20MW plus scale arrays.

Economies of scale from first of kind array installation is forecast to be in the region of €160/MWh for 20MW to 200MW capacity and €263/MWh for projects with a 2.0MW to 10MW capacity. However, it is possible that sub 10MW tidal arrays could address high cost island and weak grid demand profiles which are largely dependent upon expensive diesel fired power generation. From weak and off grid supported by diesel power project experience we see the cost of delivered power in the region €365/MWh to €570/MWh. 2.0MW prototype deployments are currently in the region of €345MWh to €784MWh based upon the limited amount of data reviewed by Wood. It is therefore possible that tidal energy could immediately support these high cost power markets subject to retaining sufficient warranty cover.

Wood's assessment of the first of a kind commercial array by considering a learning rate of 10% and 7% for capex and opex respectively covering a project development phase of 50 installations over a period of time that could be realistically be built within a 10-year time frame. The time to reach commercialisation will clearly require the assistance of grant and/or direct subsidy for the tidal stream industry to be competitive with dispatchable power sources.

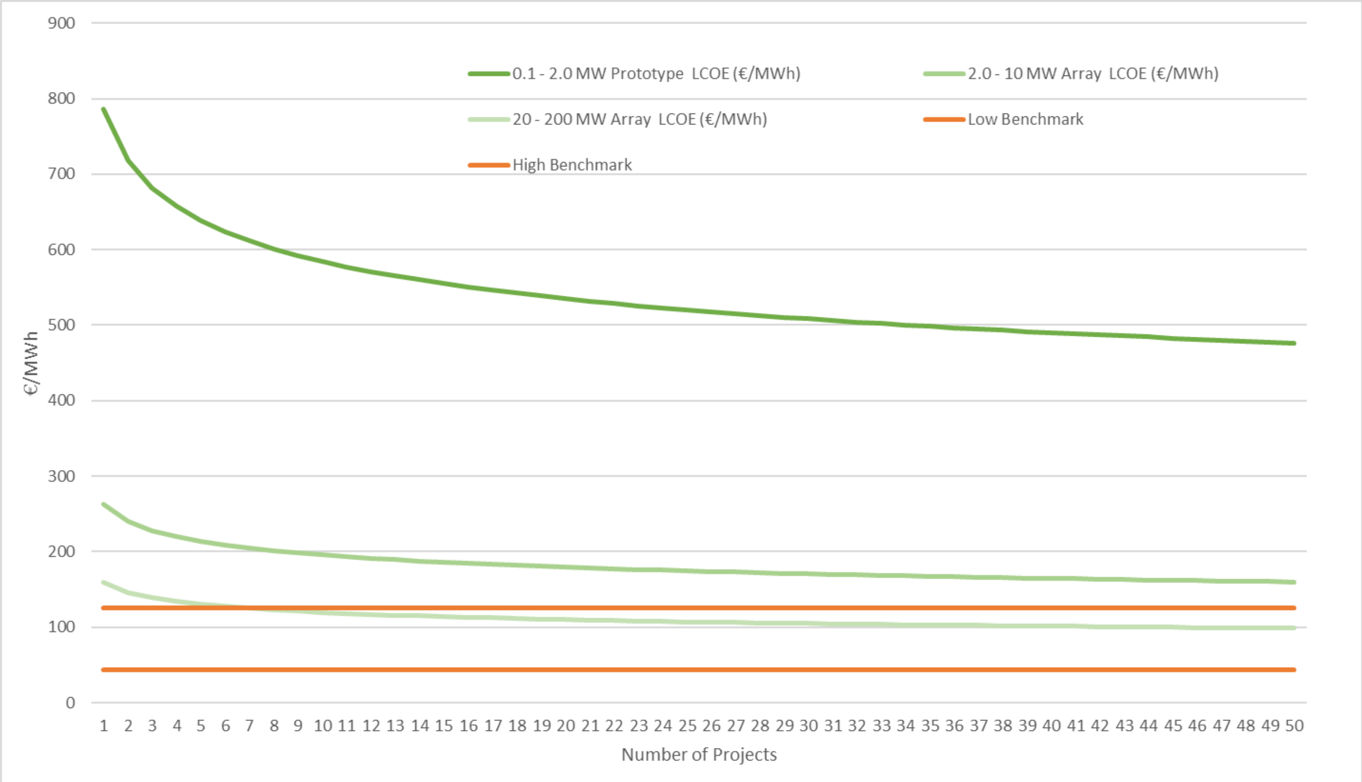

Figure 2: LCOE (€/MWh) Trajectory for Tidal Stream Compared Versus Renewable Power Benchmark[5]

[5] High and low benchmark banding based upon LCOE averages from competing power providers in the current UK/EU market.

4 LCOE Methodology

The LCOE calculation is commonly used in the power industry to rigorously compare different methods of sourcing electricity. It considers all costs of generating electricity, including capital costs, operating expenses, taxes and the cost of debt and equity. The wider capital goods sector regularly applies learning rates to evidence historical and projected cost reduction (sub-sectors include - aviation, transport, heavy engineering and offshore wind) which can be utilised in capex and opex input costs to forecast tidal stream LCOE.

Table 2 provides the representative learning rates from comparable industries to the tidal stream sector. Benchmark learning rates achieved in heavy engineering has on average delivered 13.7%. Although learning and performance gains are not pre-ordained, they do require a willingness to invest and support new technologies to the point where they can organically grow and develop. For the tidal stream sector, it is vital that regulatory support is provided if it is to realise its commercial potential.

Table 2: Benchmark Learning Rates

Offshore wind[6]	17%
Aerospace	15%
Shipbuilding	15% - 20%
Machine Tools (new models)	15% - 25%
Electronics (repetitive)	5% - 10%
Electrical Wiring (repetitive)	15% - 25%
Machining	5% - 10%
Manual Assembly	10% - 20%
Welding (repetitive)	10%
Average	13.7%

Our LCOE model has assumed a prudent learning rate of 10% and 7% for capex and opex respectively which is substantially below that seen in the offshore wind sector. Manufacturing learning rates in offshore wind has resulted in a steeper decline in opex costs due to the following key enablers:

- Increased WTG rated capacity lower overall servicing costs
- Increased availability through lower loads and therefore less maintenance
- Reduced economic margins for full service O&M providers
- Rapid deployment to 22GW enabling/supporting O&M supply chain development.

Due to the very early stage of development of tidal energy and the possibility that floating tidal will skew opex costs versus sea bed fixed we have assumed a conservative 7% rate of learning for tidal energy. We view this opex learning rate to be credible based upon sea bed fixed demanding heavy lift support vessels particularly if rated tidal turbine capacity increase in the years ahead.

We have not included decommissioning costs in our LCOE calculation due to the uncertainties regarding floating versus sea bed fixed and the likely scale of tidal turbine rated capacity, in addition to scrap and grid access value retaining the potential to recover these forecasted costs. The predicted cost to decommission multi-MW scale offshore wind has fallen dramatically in recent years due to the economy

[6] Innovation Outlook: Offshore Wind, International Renewable Energy Agency 2016 – learning rate used to predict LCOE and therefore inclusive of capex and opex inputs. Wood also compared historical cost reduction from offshore wind farms operating since 2006 to proposed projects with a COD (Commercial Operation Date) of 2023. From this data the implied learning rate was equal to 16%. This suggest further aggressive cost reduction moving forward for offshore wind.

of scale from larger turbines. The average cost to decommission a single offshore wind turbine within an array is circa €1.0m. However, as rated turbine capacity has more than doubled, the cost for decommissioning has commensurately halved. It is worth considering the scrap and grid access value maybe equal to or greater than the decommissioning costs per offshore wind turbine.

Due to the dynamic and harsh environment within the marine environment we believe that it is likely the rate of learning will be more complex to achieve the cost reductions delivered in comparison to the wind sector. That said, is clear that repeat work and learning by doing can achieve cost reduction to bring the nascent tidal sector into cost alignment with dispatchable power generation sources.

The input data for the LCOE calculation came from a limited number of leading tidal energy sources in addition to our own data set of project experience. However, we recognise the input data received to date is high level and is not exhaustive.

In
Table 3, we provide the inputs utilised in our LCOE financial model.

Table 3: LCOE Model Inputs

Tidal Turbine Unit Rated Capacity (MW)	Assumed tidal turbine rating of 1MW adjusted for cost, availability and capacity factor. Details shown in Appendices 6.
Project installed capacity (MW)	Tidal turbine nameplate (or rated capacity) of the unit deployed within each Project type: single prototype 0.1 -2.0MW, 2.0 – 10MW and 20 – 200MW arrays.
Project life expectancy (years)	Project lifetime was assumed to be 20 years in all cases for consistency. No terminal value or costs assumed
Discount Rate (%)	A discount rate of 8% used to account for the time value of money by calculating the present value of future costs. 8% assumed in all cases for consistency. It is expected that discounts rates will vary with specific project risk and the prevailing risk-free rate of borrowing also influencing the price.
Capital Expenditure (€/MW)	Sum of all capital expenditures. Details shown in Appendices 6.
Grid connection (€/MW) per annum	Cost of all electrical connections needed to connect the tidal array to the network. Assumed identical grid connection costs for consistency. Grid connection costs are assumed at €25k/MW in our LCOE model.
Overall Opex (€/MW per year)	Sum of all Operational Expenditures. They are spread over the lifetime of the project and may be broken down into sub headings such as annual O&M costs, insurance and sea bed lease rates. Cost of all planned maintenance and repair requirements associated with the upkeep of the turbine. Opex costs assumption shown in Appendices 6
Capacity factor (%)	The capacity factor is a measurement of the average production of a project over a period of time. It is calculated by comparing the amount of actual energy production during a given period to its theoretical output if it were possible for the plant to operate at full rate power over this same time period. The capacity factors assumed in our LCOE model is 30% for single prototypes and 2 – 10MW arrays and 32% for 20 – 200MW arrays.
Availability (%)	Availability of a marine energy conversion system to be in a state to perform a necessary function under given conditions at a given instant of time or over a given duration. Availability assumed in our LCOE model is 90% for single prototypes and 2 – 10MW arrays and 92% for 20 – 200MW arrays.

5 Detailed Project Financial Model

5.1 Introduction

The successful development of the tidal stream sector is largely driven by the technical engineering challenges. However, to understand the relative competitive strength of the sector requires a thorough knowledge of financial modelling at each stage of development. The financial model will act as a steer to visualise the levelised cost of energy (LCOE) as well as the return demanded by investors and banks to reach financial close.

The return on investment (ROI) for tidal stream are explored in detail through the construction of a full financial model. This facilitates the identification of key variables affecting the project value and enables financing decisions to be made in a more considered manner.

The following sections describe the key items and assumptions that would be required for the financial modelling of a typical tidal stream project and discuss the conclusions that can be drawn from the results of the modelling process.

5.2 Project Economics and Financial Modelling Results

A project financial model will calculate a range of project value indicators in order to allow developers, lenders, investors and relevant government bodies to assess the project economics from several perspectives.

From an investor’s point of view, a project is generally considered to be a reasonable investment only if the internal rate of return (IRR) is higher than the weighted average cost of capital (WACC). Investors will have access to capital at a range of costs; the return arising from investment of that capital must be sufficient to meet the costs of that capital. Moreover, the investment should generate a premium associated with the perceived risk levels of the project.

Renewable energy projects are usually financed with equity and debt components. As a result, the IRR for the equity component can be calculated separately from the IRR for the project as a whole. The developer’s decision to implement the project or not, will be based on the equity IRR.

As returns generated in the future are worth less than returns generated today, a discount can be applied to future cash flows to present them at their present value. The sum of discounted future cash flows is termed the net present value (NPV). Investors will seek a positive NPV, assessed using a discount rate that reflects the WACC and perceived risk levels of the project. Lenders will be primarily concerned with the ability of the project to meet debt service requirements. This can be measured by means of the debt service coverage ratio (DSCR). This is the cash flow available to service debt divided by the debt service requirements. The Average DSCR represents the average debt serviceability of the project over the debt term. A higher DSCR results in a higher capacity of the project to service the debt. Minimum DSCR represents the minimum repayment ability of the project over the debt term.

A minimum DSCR value of less than one indicates the project is unable to service the debt in at least one year. Lenders will conduct sensitivity analysis around the key variables in order to determine whether the project will be able to service the debt in a bad year, for example if the energy yield is lower than expected, or operational expenditure is higher than expected.

5.2.1 Financing Assumptions

The project financing structure generally comprises of debt and equity.

Renewable energy projects may typically have a debt and equity mix with the following broad terms:

- Financing structure - equity 20% to 25% and debt 80% to 75%.
- Debt repayment period of between 8 and 12 years.
- Debt service cover ratio of at least 1.3 times.

It should be noted the pre-commercial scale projects are unlikely to attract project finance unless this includes the use of soft loans from government agencies.

5.2.2 Sensitivity Analysis

Sensitivity analysis involves changing the inputs in the financial model (such as CfD, /off-take price capital cost and energy yield) to analyse how the value of the project changes, measured by the NPV, IRR, or the DSCR.

Sensitivity analysis gives lenders and investors a greater understanding of the effects of changes in inputs such as power tariffs on the project's profitability and bankability. It helps them understand the key risks associated with the project.

Typical results that are monitored during sensitivity analysis include:

- Post tax Project IRR.
- Post tax Equity IRR.
- Average DSCR.
- Minimum DSCR.

Typical variables investigated during sensitivity analysis include:

- Capital costs.
- Operational costs.
- Annual energy production.
- Interest rate.

5.2.3 Developers Fees

Where debt and equity investors seek to purchase a tidal stream project from a developer; the vendor (the developer/owner) will normally seek to profit from their activities. This level of profit or return will be driven by three key variables namely:

- The developer cost of taking the project to construction ready financeable state.
- The cost of building and operating the tidal stream project.
- The net IRR (after buying out developer/vendor) to the acquiring investor.

At this stage, the tidal stream sector is too immature to attract active mergers and acquisitions (M&A) activity. However, it is likely once commercial arrays can be built through a government regulated structure (e.g. CfD or green certificate) investors and banks will be drawn to this market segment. It is clear that investment in renewable energy infrastructure remains strong and this is manifested in a widening of the investor base in addition to the lowering of the acquired IRR and WACC. It is highly credible tidal stream will also play a part within the renewable energy infrastructure sector.

5.2.4 Key Analysis in the Financial Model

The financial model should include the following key standard accounting practices in the cash flow/income statement:

- DSCR reflects the amount of free cash flow available to meet interest and capital repayments over the term of the debt.
- Cash Flow Available for Debt Service (CFADS), method to size and term of debt structure reflecting cash waterfall net of capex, opex and working capital adjustments.
- Loan Life Coverage Ratio (LLCR) provides a measure of the credit quality of the project which is the NPV of the CFADS.
- Maintenance Reserve Account (MRA), to cover contingencies such as inverter replacements.

The crucial driver of the revenue line in the cash flow model and income statement is the energy yield prediction. This must be prepared by at least one experienced independent and suitably qualified renewable energy consultant who is able to provide 'bank grade' energy yields.

5.3 Key Financial Model Inputs

A financial model is needed to assess the viability of any renewable project development to meet the demands of the project owner and its third-party investors (debt servicing capability and equity investment return). The key input costs and revenues driving the financial model results in the form of LCOE will vary depending upon project specifics and its regulatory environment.[7] Table 4 provides typical inputs in the financial model.

[7] Regulatory variable inputs include; feed-in tariff, tax investment credit, traded green certificate, grants/soft loans, grid connection costs inclusive or exclusive of project costs, development costs removed/pre-paid by government and lease arrangements.

Table 4: Key Financial Model Inputs

Inputs	Comments
Project size (MW)	Based upon feasibility/technical study reflecting the restraints of grid capacity and seabed conditions combined with the energy yield prediction to reference project capacity (e.g. MW's).
Energy yield/capacity factor	Calculated reflecting tidal resource, turbine efficiency/rated capacity, lifetime degradation, electrical losses, turbine availability.
Tariff and other revenue streams	The price for power in the PPA along with other incentives needed to determine project revenues.
Capex costs	One-off costs for the construction and commissioning of the project, generally based on an EPC contract. Includes export and inter array cabling costs and balance of plant cost to dispatch power to the grid.
Opex costs	Normally a 20/25-year view of costs, which are based upon initial contract agreements (e.g. O&M, land rent/lease, and corporate overheads, including legal and accounting costs) that will be subject to adjustments for inflation and other variables.
Debt service and repayment costs	This involves the repayment of debt interest and capital over a defined pre-agreed period with the lender (debt length normally equal to contractual period of the PPA).
Grid tolling costs	Potential grid access fee, if applicable.
Taxes	Payment of central and local government taxes.

Critical decisions made throughout the development process are largely based around the outputs from the financial model. Detailed engineering costing needs to be properly reflected in the model so that the correct strategic decisions can made to reach a successful financial close.

6 Executive Summary and Conclusions

In Tables 5, 6, and 7 we provide the outputs from our LCOE analysis incorporating single prototype scale to large array deployments. Overall, we estimate that LCOE for larger arrays could fall below €100/MWh by the time 1GW of capacity has been installed which is broadly in line with Offshore Renewable Energy Catapult's May 2018[8] estimated LCOE of £90/MWh (€103/MWh) by 1GW of installed capacity.

The current LCOE for tidal energy is comparable to the first of a kind wind and solar LCOE demonstrated in the early 2000's. It is clear from the evidence that a favourable legislative environment allows for repeat learning and therefore cost reduction. There is no fundamental reason why tidal energy cannot experience similar levels of cost and efficiency improvements. By encouraging the expansion of tidal energy, it will facilitate a more diversified and complementary generation profile to meet the needs of balancing the grid, in step with permanently and sustainably reducing carbon emissions.

[8] https://s3-eu-west-1.amazonaws.com/media.newore.catapult/app/uploads/2018/05/04120736/Tidal-Stream-and-Wave-Energy-Cost-Reduction-and-Ind-Benefit-FINAL-v03.02.pdf

Appendix I

Tables 5, 6 and 7 evidence the outputs from our modelled LCOE curves provides in the Figure 2.

Table 5: Single Prototype LCOE Data

Number of Projects	0.1 - 2.0 MW Single Prototype Cost (€'000/MW)	0.1 - 2.0 MW Prototype Opex Cost (€'000/MW)	0.1 - 2.0 MW Prototype LCOE (€/MWh)
1	9,918	787	786
2	8,926	732	719
3	8,393	701	682
4	8,034	680	657
5	7,766	665	639
6	7,553	652	624
7	7,378	642	612
8	7,230	633	601
9	7,102	625	592
10	6,989	618	585
11	6,889	612	578
12	6,798	606	571
13	6,716	601	565
14	6,641	597	560
15	6,571	592	555
16	6,507	588	551
17	6,448	585	546
18	6,392	581	542
19	6,339	578	539
20	6,290	575	535
21	6,244	572	532
22	6,200	569	529
23	6,158	566	526
24	6,118	564	523
25	6,080	562	520
26	6,044	559	518
27	6,010	557	515
28	5,977	555	513
29	5,945	553	511
30	5,914	551	508
31	5,885	549	506
32	5,856	547	504
33	5,829	545	502
34	5,803	544	500
35	5,777	542	499
36	5,753	541	497
37	5,729	539	495
38	5,705	537	493
39	5,683	536	492
40	5,661	535	490
41	5,640	533	489
42	5,619	532	487
43	5,599	531	486
44	5,580	529	484
45	5,561	528	483
46	5,542	527	482
47	5,524	526	480
48	5,506	524	479
49	5,489	523	478
50	5,472	522	477

Table 6: Medium Array LCOE Data

Number of Projects	2.0 - 10 MW Array Capex Cost (€'000/MW)	2.0 - 10 MW Arrray Opex Cost (€'000/MW)	2.0 - 10 MW Array LCOE (€/MWh)
1	3,602	217	263
2	3,242	201	240
3	3,048	193	228
4	2,918	187	220
5	2,821	183	214
6	2,744	180	209
7	2,680	177	205
8	2,626	174	201
9	2,580	172	198
10	2,539	170	196
11	2,502	169	193
12	2,469	167	191
13	2,439	166	189
14	2,412	164	188
15	2,387	163	186
16	2,364	162	185
17	2,342	161	183
18	2,322	160	182
19	2,303	159	181
20	2,285	158	179
21	2,268	157	178
22	2,252	157	177
23	2,237	156	176
24	2,222	155	175
25	2,209	155	175
26	2,195	154	174
27	2,183	153	173
28	2,171	153	172
29	2,159	152	171
30	2,148	152	171
31	2,137	151	170
32	2,127	151	169
33	2,117	150	169
34	2,108	150	168
35	2,098	149	167
36	2,089	149	167
37	2,081	148	166
38	2,072	148	166
39	2,064	148	165
40	2,056	147	165
41	2,049	147	164
42	2,041	146	164
43	2,034	146	163
44	2,027	146	163
45	2,020	145	162
46	2,013	145	162
47	2,006	145	161
48	2,000	144	161
49	1,994	144	161
50	1,988	144	160

Table 7: Large Array LCOE Data

Number of Projects	20 - 200 MW Array Capex Cost (€'000/MW)	20 - 200 MW Arrray Opex Cost (€'000/MW)	20 - 200 MW Array LCOE (€/MWh)
1	2,337	140	160
2	2,103	130	146
3	1,978	125	139
4	1,893	121	134
5	1,830	118	131
6	1,780	116	128
7	1,739	114	125
8	1,704	113	123
9	1,673	111	121
10	1,647	110	120
11	1,623	109	118
12	1,602	108	117
13	1,582	107	116
14	1,565	106	115
15	1,548	106	114
16	1,533	105	113
17	1,519	104	112
18	1,506	104	112
19	1,494	103	111
20	1,482	102	110
21	1,471	102	110
22	1,461	101	109
23	1,451	101	108
24	1,442	101	108
25	1,433	100	107
26	1,424	100	107
27	1,416	99	106
28	1,408	99	106
29	1,401	99	105
30	1,394	98	105
31	1,387	98	105
32	1,380	98	104
33	1,374	97	104
34	1,367	97	103
35	1,361	97	103
36	1,355	96	103
37	1,350	96	102
38	1,344	96	102
39	1,339	96	102
40	1,334	95	101
41	1,329	95	101
42	1,324	95	101
43	1,319	95	100
44	1,315	94	100
45	1,310	94	100
46	1,306	94	100
47	1,302	94	99
48	1,297	93	99
49	1,293	93	99
50	1,289	93	99

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