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Quantifying the benefits of tidal stream energy to the wider UK energy system

A 2050 case study

EXECUTIVE SUMMARY

- Tidal stream is an emerging and exciting renewable energy source, with 30-40MW of new capacity set to be announced in 2022 through the UK CfD Allocation Round 4 (AR4).
- The resource is highly predictable and can be accurately forecasted years ahead of time, unlike other renewables like wind and solar. It is also completely decoupled from other renewable resources, improving energy source diversity and providing resilience against extreme weather events.
- Tidal technology is currently expensive compared to other renewables, however it is on a steep cost reduction trajectory and has unique properties that give it advantages for a role in the wider energy system. This is because greater value can be placed on the quality of the energy (predictability and dependability), as this will reduce system costs in areas associated with balancing, reserve capacity and curtailment.

ORE Catapult commissioned a study to assess the potential benefit to the energy system. This was funded through the TIGER project[1]. Imperial College London (ICL) used their Integrated Whole Energy System (IWES) model to investigate how the introduction of tidal stream impacted the overall cost and composition of the energy system in 2050. This assumed a Net-Zero UK energy

[1] TIGER is a €45.4M Interreg funded project. The aim is to accelerate learning and cost reduction in the tidal stream sector by supporting consenting and technology deployment at six locations in the Channel region between the UK and France. For more information visit https://interregtiger.com/.

system, matching government targets. Tidal farm power output estimates were provided by the University of Plymouth, a partner in the TIGER project, and the University of Edinburgh.

Results from the study indicated the following:

- **The breakeven LCOE of tidal stream in 2050 was found to be £49-55/MWh**, depending on the capacity installed. Below this level, tidal stream offers cost benefits to the grid and will displace other renewables (for example offshore wind and biomass with CCS). Above this level, tidal stream adds cost to the system when compared to the scenario with no tidal stream.
- **Tidal stream was found to displace other renewable energy technologies and natural gas CCGT**. In the baseline scenario the tidal stream reduced the CCGT capacity by 40%: from 8.1GW to 4.9GW. This shows that tidal stream contributes to security of supply, displacing the need for peaking and flexible CCGT plant, and also contributes to reduction in emissions.
- At a LCOE of £40/MWh, the optimal solution would be to install the maximum amount of tidal stream (which ICL set to 20GW in the model). At £50/MWh the optimal system contained 3.1GW of tidal stream. The latter LCOE is 42% above the 2050 LCOE assumed for offshore wind (£35/MWh). **This shows that there is a lower system integration cost[2] for tidal stream and that a premium for energy from tidal stream is warranted**, vs installing additional wind, as it improves diversity in renewable outputs.
- **At a LCOE of £50/MWh, tidal stream could reduce system costs by £100M per annum. This rises to a saving of £600M per annum at an LCOE of £40/MWh.**
- The cost benefits to the energy system were greater when the wind resource was lower, the technology becoming more cost competitive. The P5 wind scenario increased the tidal system cost saving to £800M per year, with a breakeven LCOE of about £72/MWh**. Tidal stream energy can help mitigate against low wind events that can have implications for the whole energy system** (as was seen in 2021, where lower than average wind speeds contributed to depletion of gas reserves and hence a rise in energy prices [1]).

In broad terms, the study indicates an LCOE target of £50/MWh by 2050 for the industry. This is possible to achieve with an average deployment rate of 420MW per year and a learning rate of 10-15%, as has been achieved historically for other renewable technologies.

INTRODUCTION

Motivation

Countries across the world are rapidly decarbonising their electricity systems as a response to the growing climate emergency. Many have set legally binding net zero targets, including the UK, and have plans to phase out fossil fuel generation over the coming decades.

[2] System integration costs are defined as the additional system costs associated with balancing, and transmitting the energy from the supply to demand, securing reliable supply and meeting carbon targets.

This transition is being accelerated by current events. Recently, supply and demand mismatch in natural gas was brought about by the Covid pandemic and exacerbated by depleted European supplies. This is being made worse by the Russia-Ukraine, conflict, which saw the price of oil momentarily rise to over $120 per barrel in March 2022, the highest level for over a decade. Energy security is firmly back on the agenda, with countries keen to harness their natural resources as a way to reduce exposure to such geopolitical events.

There are many different renewable technologies vying for a role in the future energy system. These include established technologies like wind and solar PV, which have already seen widespread adoption across the world. These are at cost parity with fossil fuel generation in many markets. Costs have plummeted in recent years due to increased economies of scale, technology and financial innovations and supply chain improvements.

An issue with these technologies is that they are variable and non-dispatchable, meaning that they are not inherently available on demand. They are also difficult to forecast ahead of time. This is problematic for the wider electricity network, where supply and demand must be balanced in real time and operating frequency must be kept stable to prevent issues like blackouts.

As well as short term issues, longer term variations in intermittent renewable resources (such as inter-annual variability) can also be problematic for the wider energy system and have implications for energy security. For example, 2021 has had lower than average wind speeds across Europe [1]. This meant that gas had to supply more generation, depleting reserves and increasing gas prices further. From increasing gas usage follows increased greenhouse gas emissions, which hinders national efforts to meet emissions targets. If such intermittent sources are not available for sustained periods then the energy must be provided instead by dispatchable, polluting technologies or energy imports, sometimes at substantial cost

There are also balancing costs to consider. For example, many wind farm operators are paid to switch off their turbines during periods of high supply and low demand (known as curtailment). Equally, during periods of low supply (i.e. when wind and solar resources are low), CO_2 emitting generators such as CCGT plants are paid to come online. These costs are incurred by the network operator, rather than by the renewable farm operator, and so are often overlooked and not factored into economic assessments at a project level.

What is the cost premium to the energy system?

One recent study that attempted to quantify the additional costs to the energy system was published by the UK Government Department for Business, Energy & Industrial Strategy (BEIS): *Electricity Costs 2020* [2]. This introduced the concept of enhanced LCOE, a metric combining conventional project costs with the costs incurred within the electricity system (factoring in the location of the generation, its timing and the balancing required). This applied methodology devised by Frontier Economics and published in their 2016 report: *Whole power system impacts of electricity generation technologies* [3].

When factoring in these additional system costs, BEIS estimated the LCOE of wind and large scale solar to be 20-50% higher than their baseline estimates in some scenarios, as shown in Figure 1 (the different scenarios represented by the blue diamonds).

Frontier Economics point out that tidal stream will not add to balancing costs, due to the fact that the tides can be forecasted with "near certainty". They also note that, because there is no correlation between the tidal and wind resource, they compliment each other well in providing smoother power output and diversification in the energy supply.

Tidal stream: a solution

Tidal stream energy has unique properties that could benefit the system and reduce costs. The technology consists of underwater turbines that generate electricity from tidal flows in much the same way as wind turbines do above the waterline (you can think of them much like underwater wind turbines!). Figure 2 shows four of the leading tidal technologies. Suitable tidal flows tend to occur in the channels between islands and around headlands, where the water is focussed by the natural topography of the seabed.

Almost all renewable energy resources originate from the Sun. Solar panels capture the Sun's energy directly. Wind is a form of second hand solar, the differential heating of the Earth's surface driving atmospheric winds.

Tidal energy is generated by the relative movements between the Earth, Moon and Sun. This means that it is completely decoupled from other renewable resources and can also be forecasted hundreds of years into the future. This makes the power output firmer and more dependable, with consistent peaks in tidal flow each day. Tidal sites also tend to be close to shore (<5km), reducing the cost of subsea cables. Some notable tidal sites are also close to population centres, for example the Perputuus Tidal Energy Centre (PTEC) to the south of the Isle of Wight. Tidal devices have also benefitted from offshore wind innovations and supply chain improvements and there are conceptual similarities (for example the horizontal axis turbine and foundation design).

A new dawn

Despite key advantages, tidal stream is yet to break into the mainstream. Across the world, progress to date has largely been individual device deployments to demonstrate proof of concept.

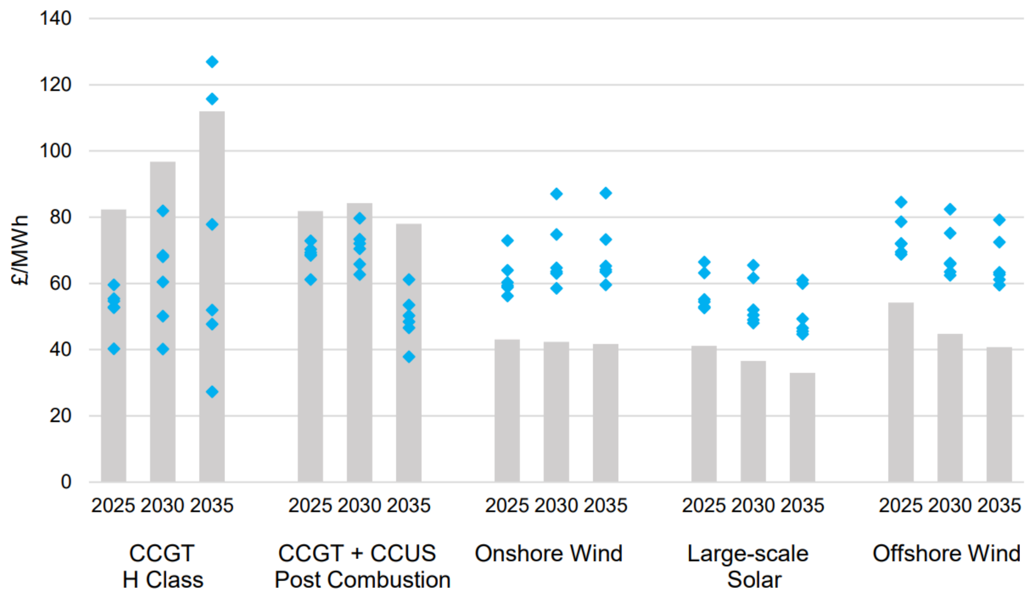


Figure 1 – Enhanced LCOE for five different technologies (blue diamonds), taken from the Electricity Generation Costs 2020 report [2].

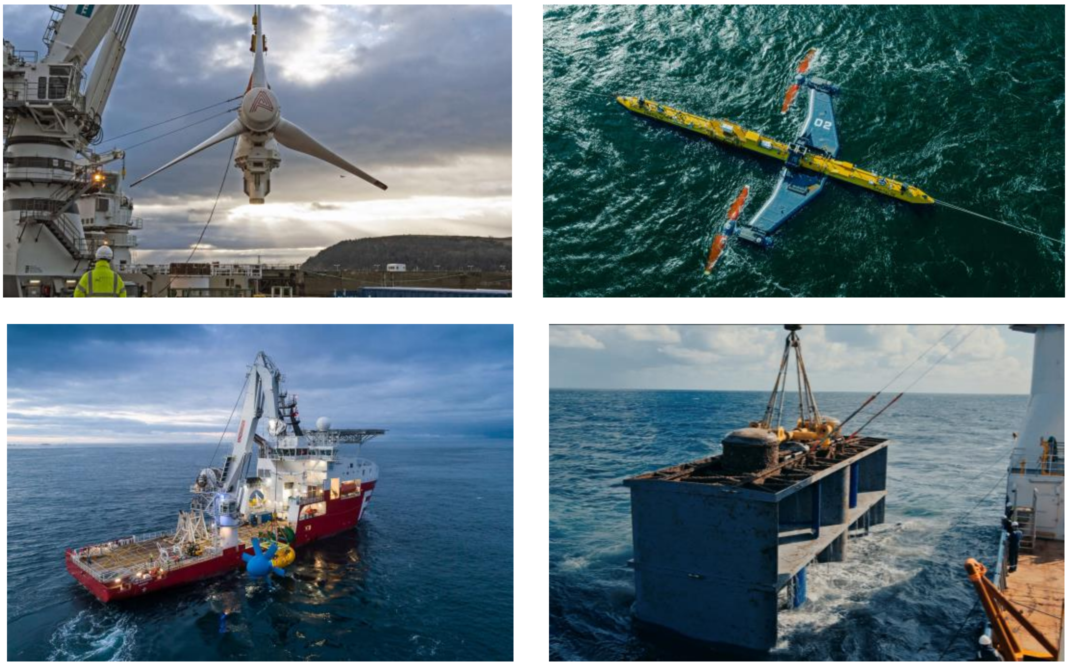


Figure 2 – Devices from four of the leading tidal stream device developers. Top-left: SIMEC Atlantis AR1500; Top-right: Orbital Marine Power O2; Bottom-left: Sabella D10; Bottom-right: Hydroquest OceanQuest

There are only two arrays deployed in the UK: Meygen in the Pentland Firth (owned by SIMEC Atlantis Energy) and the Shetland Array (owned by Nova Innovation). In total, as of January 2022, there was 11.5MW in the water across Europe [4], the majority in the UK, compared to 10,400MW of offshore wind in the UK alone.

The industry is much younger than the wind industry. While the industry has benefitted from some synergies with wind technology, as previously mentioned, the resource does introduce unique challenges. Extreme tides give a shorter weather window for operations and makes working offshore more difficult, as DP vessels are typically required. The loading regime is also different to wind, and the rotors and other components are submerged so water ingress becomes a more important consideration. The accelerated expansion and plummeting costs of offshore wind has, to some degree, taken attention away from emerging technologies like tidal stream energy.

In the UK, tidal stream has lacked access to revenue support since 2016, with developers relying on grant funding, crowd funding and private investment. This is set to change, with £20M per annum ringfenced by the UK Government in CfD Allocation Round 4 (AR4). From this, 30-40MW of new tidal capacity is expected [5] which will be commissioned by 2025-26. If tidal stream can show success with these projects, following a credible cost reduction pathway and demonstrating reliable operation, this should pave the way for participation in future CfD rounds. This will unlock further technological innovation, investment from the private sector, and cost reduction through upscaled deployment.

QUANTIFYING THE SYSTEM BENEFITS OF TIDAL STREAM: A NEW STUDY

In 2021, the Offshore Renewable Energy Catapult (ORE Catapult) commissioned a study to quantify the impacts of tidal stream on the electricity system. This was funded through the TIGER project, a €45.4M Interreg funded project with the aim of accelerating the industry by helping project developers to obtain consents and deploy new technology at six locations across the UK and France[3].

From the study we wanted to gain insight into the following aspects:

- Can tidal stream lower the costs of the wider electrical system?
- How much tidal capacity could be economically deployed, given the scale and costs of other renewables?
- What LCOE is needed to justify large scale deployment of tidal stream, from a system cost perspective?

To answer these questions, we commissioned Imperial College London (ICL) to model a number of tidal stream scenarios using their Integrated Whole Energy System (IWES) model.

IWES is a least-cost optimisation model, visualised in Figure 3. It can simultaneously minimise long-term investment and short-term operating costs across multi-energy systems (electricity, heating, hydrogen) from the supply side. It models the full energy network, to the end-customers, while meeting the required carbon targets and system security constraints. The IWES model has been used for several key pieces of work, some of which have been used to advise the UK government on energy policy and strategy. For example, in 2018 ICL used the model to advise the Committee on Climate Change (CCC) on heat decarbonisation pathways, which was used as evidence to support the CCC's 2018 progress report to Parliament [6]. More recently it was used to assess flexibility in the UK energy system for the Carbon Trust [7].

[3] For more information visit https://interregtiger.com/

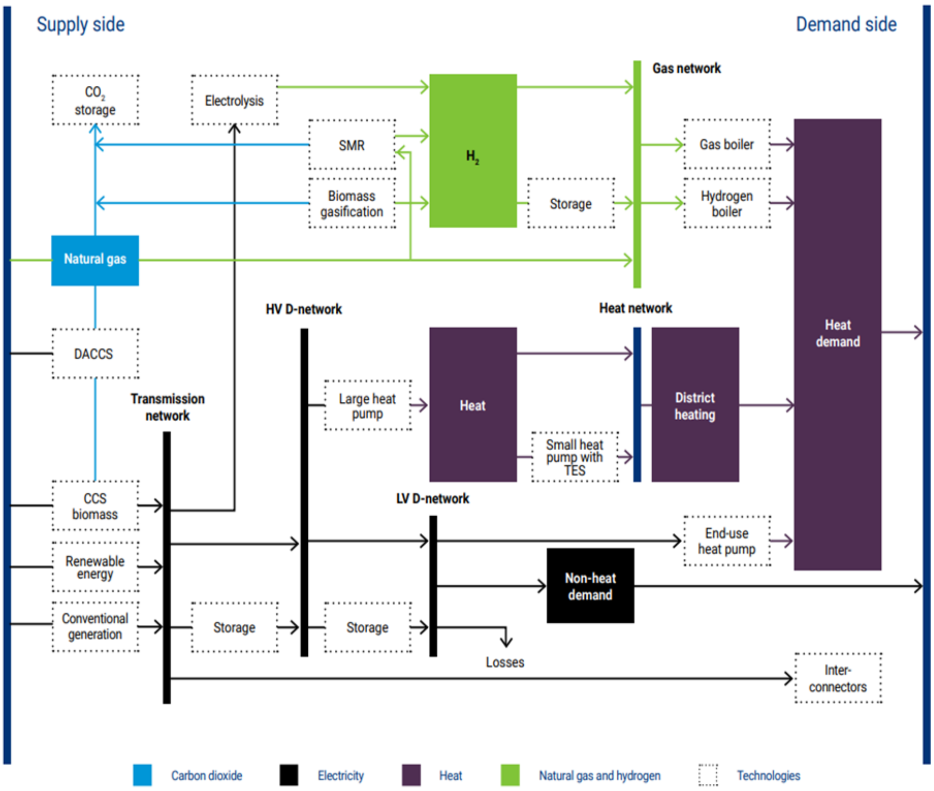


Figure 3 – The Integrated Whole Energy System (IWES) Model [12].

The key model output is the net cost of the whole energy system in 2050. Countless model sensitivities can be probed to see how this overall cost is affected, and the whole system can be optimised for the lowest system cost, given technology specific costs and performance characteristics.

Research method

We used the UK as a case study, assuming a net zero energy system by 2050.

For the IWES model, ICL needed the locations and power output profiles of the tidal farms assumed for 2050. This data was supplied by University of Plymouth, a TIGER partner, and the University of Edinburgh, who have various models of the tidal current resource covering the UK. The locations and capacities were selected according to the Carbon Trust study *UK Tidal Current Resource and Economics Study* [8]. This provides locations and annual production estimates for about 30 sites across the UK, subject to environmental constraints. The University of Plymouth generated power time-series for farms at each site by quantifying the power capacity of each site and assuming a capacity factor of 40%. They checked the installed capacities in the Carbon Trust study against more recent estimates, updating where appropriate. This resulted in a baseline installed capacity of 11.8GW.

ICL built a model of the UK energy network by integrating this data into their existing model. They ran a number of sensitivities including:

- Varying the tidal stream installed capacity on the system.

- Varying the tidal stream LCOE.
- Varying the wind resource (P5 and P95) to see how this changed the benefit from tidal stream.
- Varying the tidal turbine power coefficient, to examine the impact of future technology improvements.

KEY FINDINGS

The simulation results offer deep insight into how tidal stream could impact the balance of the 2050 energy system. Across the analyses, the IWES modelling shows the following:

- The breakeven LCOE of tidal stream was found to be £49-55/MWh, depending on the capacity installed. Below this level, tidal stream offers cost benefits to the grid and will displace other renewables (for example offshore wind and biomass with CCS). Above this level, tidal stream adds cost to the energy system when compared to the cost-optimised scenario with no tidal stream.
- Tidal stream was found to displace both renewable energy technologies and natural gas CCGT (NG CCGT), as shown in Figure 4. In the base case, tidal stream was found to reduce the NG CCGT capacity required by about 40%: from 8.1GW to 4.9GW. Currently more than half of UK gas is imported [9], with recent prices extremely high due to geo-political events, and so a thriving domestic tidal industry could significantly contribute to improved energy security.
- At a LCOE of £40/MWh, the model recommended installing the maximum amount of tidal stream onto the system (which ICL modelled as 20GW). At £50/MWh the optimal system contained 3.1GW of tidal stream. The energy system compositions are shown in Figure 5. The latter LCOE is 42% above the 2050 LCOE assumed for offshore wind (£35/MWh), showing that a premium for tidal stream is warranted, vs installing additional wind, as it improves diversity in renewable outputs.
- At a LCOE of £50/MWh, tidal stream could reduce system costs by £100M per annum. This rises to a saving of £600M per annum at an LCOE of £40/MWh.
- The cost benefits were greater when the wind resource was lower, the technology becoming more cost competitive. The P5 wind scenario increased the tidal system cost saving to £800M per year, with a breakeven LCOE of about £72/MWh.
- The base case was considering the average power coefficient that has been demonstrated at the Meygen project (0.41 [10]). This represents the efficiency of the turbine in converting the tidal flow to energy[4]. Increasing this to 0.5 (to represent future technology improvements)

[4] "Water to wire", to the point that the power is exported to shore. An additional 4% in losses were added to account for availability and electrical losses.

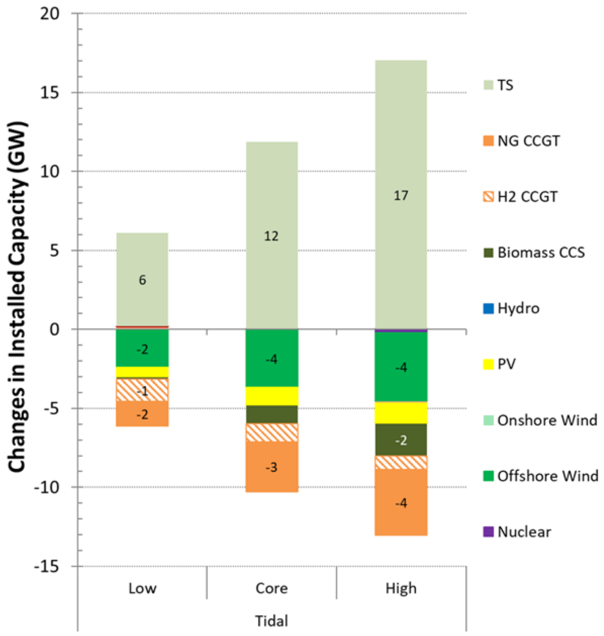


Figure 4 – The tidal stream added to the energy systems in the three capacity scenarios that were examined and the technologies that it displaced.

resulted in a £1.1Bn per annum system cost saving at a £40/MWh LCOE and a similar £100M per annum at £50/MWh LCOE.

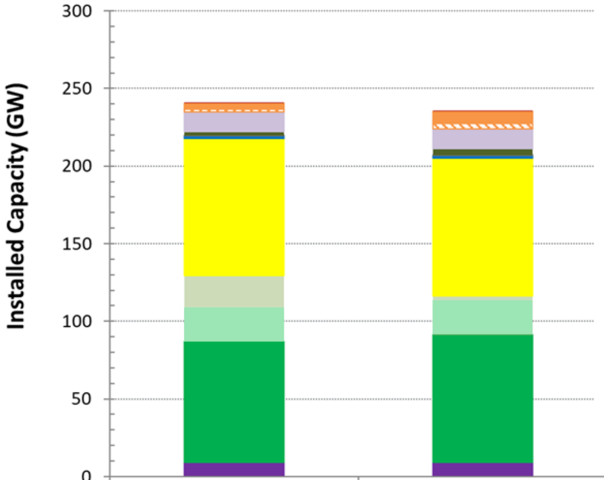
How does this align with cost projections?

Arguably the main finding from this study is the £49-55/MWh breakeven tidal stream LCOE by 2050. While certain aspects of the tidal technology could warrant a cost premium (for example the high predictability), from a purely economic perspective this is the level that the tidal technology must reach to start to reduce the costs of the overall energy system.

So how achievable is this? The current LCOE of tidal stream is in the range £250-300/MWh, depending on the technology and site conditions. This is reflected by the administrative strike price set for AR4, at £211/MWh (2012 currency, £254 in 2021 currency). Greater insight will be gained when the successful bids are announced later this year.

The sector has seen rapid cost decrease in the last five years, even without revenue support. LCOE in 2015 was estimated at $440/MWh by Bloomberg New Energy Finance (BNEF) [11], equivalent to £380/MWh in 2021 currency. From 2015 to 2022 this implies a 33% LCOE reduction, a significant amount despite only a handful of turbine installations and one multi-MW array with government revenue support (Meygen, a 6MW project).

Projections by Coles et al. estimate that tidal stream could dip below £150/MWh by 2030 if it keeps on its current cost reduction trajectory (assuming a learning rate of 17%) and the 124 MW of capacity that is currently eligible to bid into subsidy support auctions is installed [12]. Projections by ORE Catapult have estimated that tidal stream could reach £90/MWh by the time 1GW has been installed, which could be achieved by the early 2030s if upcoming projects can capitalise on the strong sector headwinds at present. The Marine Energy Council (MEC), an industry body made up of leading tidal technology developers and suppliers, is calling on the government to adopt a 1GW installed capacity of wave and tidal stream by 2035 (the majority of this will be tidal stream).



	TS £40/MWh	TS £50/MWh
NG OCGT	0.0	0.1
NG CCGT	3.9	7.9
H2 OCGT	0.0	0.0
H2 CCGT	1.9	3.4
Storage	12.7	12.7
CCS	0.0	0.0
Biomass CCS	2.7	4.6
Coal CCS	0.0	0.0
Hydro	1.5	1.5
PV	88.6	89.0
TS	20.8	3.1
Onshore Wind	21.5	21.6
Offshore Wind	78.0	82.3
Nuclear	9.0	9.3

Figure 5 – Optimal power generation portfolio for tidal stream LCOE of £40/MWh and £50/MWh

Our projections indicate that a learning rate of 10-15% would be enough to achieve an LCOE of £50/MWh by 2050 (assuming 10GW installed), which compares favourably to learning rates seen for more established technologies (e.g. the long term learning rate of offshore wind is about 14% [13]).

SUMMARY

The predictability, regularity and unique nature of the tidal resource primes it for a future role in the energy system. The modelling from ICL indicates a target LCOE of £49-55/MWh to make the economic case from the energy system perspective, which is possible if the industry continues on its current cost reduction trajectory.

There are additional benefits of tidal which we have not explored here. These include gross value added (GVA), jobs created, export potential and the potential to revitalise local coastal communities. Moreover, there could be benefits from integrating short term storage directly into tidal projects, allowing the technology to provide a consistent baseload of power. We plan to examine these areas within future projects.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. Danny Pudjiano and Prof. Goran Strbac (Imperial College London); Dr. Daniel Coles (University of Plymouth); Dr. Athanasios Angeloudis (University of Edinburgh); Gavin Smart, Mohammed Almoghayer and Simon Cheeseman (ORE Catapult) for their advice and inputs into this study.

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Appendices

RECOMMENDED READING

G. Smart: What does the BEIS CfD AR4 announcement mean for the tidal stream energy sector?

D. Coles et al: A review of the UK and British Channel Islands practical tidal stream energy resource (Proc. R. Soc. A. 477: 20210469. 20210469)

Imperial College London: Analysis of Alternative UK Heat Decarbonisation Pathway, for the Committee on Climate Change

AUTHOR PROFILE

Dr Ciaran Frost is a techno-economic analyst at the Offshore Renewable Energy Catapult. Ciaran holds an Engineering Doctorate (EngD) in Offshore Renewable Energy from the Industrial Doctoral Centre for Offshore Renewable Energy (IDCORE) and a Master of Physics from the University of Warwick. Ciaran specialises in techno-economic assessment of marine renewable energy technologies, applying his advanced knowledge of the Python programming language, GIS and Microsoft Excel.

Ciaran is currently leading techno-economic analyst on the TIGER project. This €45.4M Interreg funded project aims to accelerate cost reduction and innovation in tidal stream energy by assisting with development of six tidal sites in the UK and France.

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