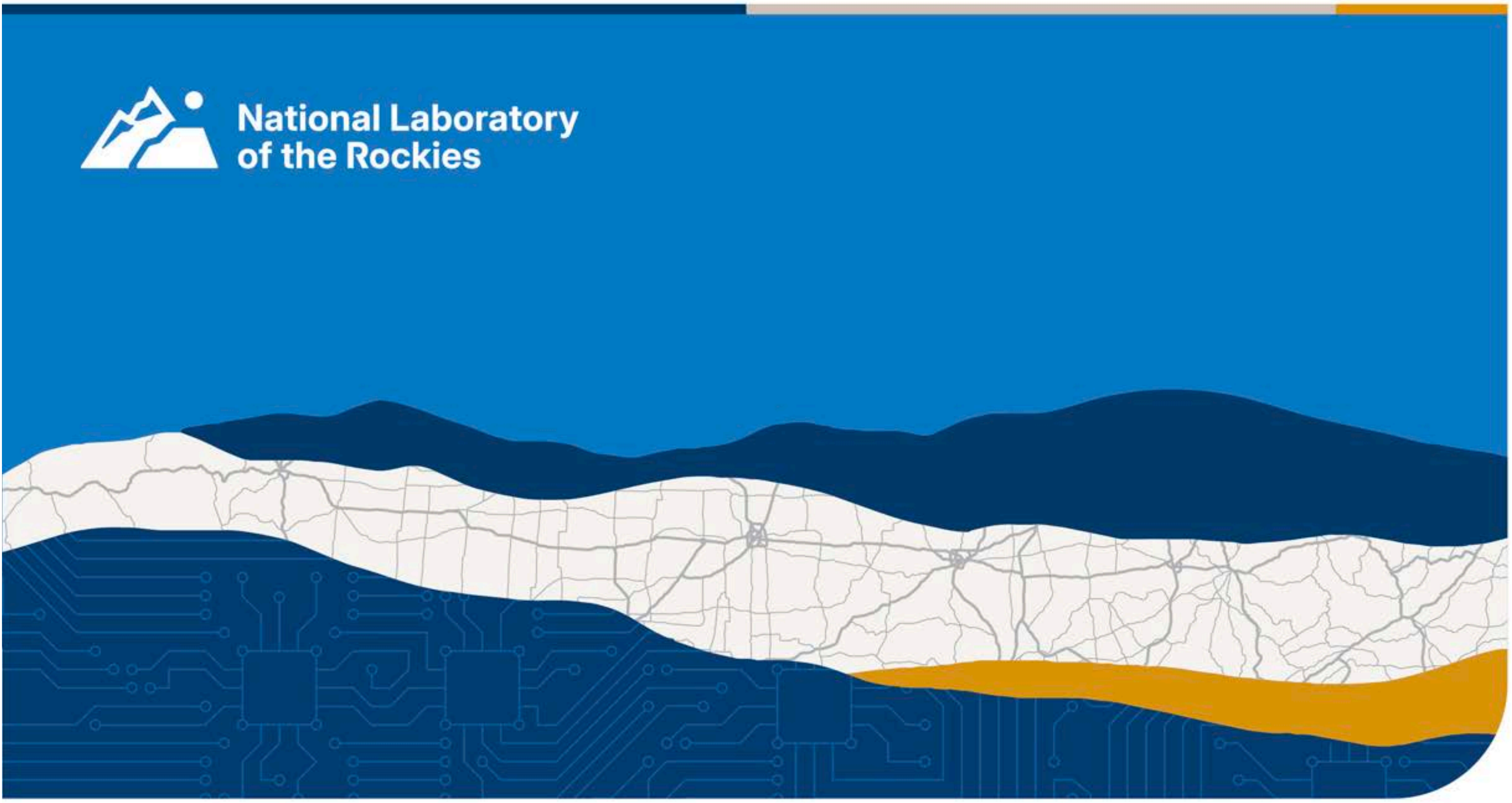

Expert Elicitation for Tidal Energy Levelized Cost of Energy: Present and Future

Elena Baca[1] and Jonathan Colby[2]

1 National Laboratory of the Rockies
2 Streamwise Development LLC

The National Laboratory of the Rockies is a national laboratory of the U.S. Department of Energy, Office of Critical Minerals and Energy Innovation, operated under Contract No. DE-AC36-08GO28308.

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List of Acronyms

AR	allocation round
CapEx	capital expenditures
CF	capacity factor
CfD	contract for difference
DOE	U.S. Department of Energy
GPRA	Government Performance and Results Act
GW	gigawatt
H2O	Hydropower and Hydrokinetic Office
IEA OES	International Energy Agency Technology Collaboration Programme on Ocean Energy Systems
IEC	International Electrotechnical Commission
km	kilometer
kWh	kilowatt-hour
LCOE	levelized cost of energy
m	meter
MW	megawatt
MWh	megawatt-hour
NHA-MEC	National Hydropower Association Marine Energy Council
OpEx	operational expenditures
R&D	research and development
SET-Plan	Strategic Energy Technology Plan
TWh	terawatt-hour
USD	U.S. dollars

Executive Summary

Tidal energy is an emerging marine energy technology that has the potential to contribute up to 220 terawatt-hours per year of renewable energy generation in the United States (Kilcher, Fogarty, and Lawson 2021). Since 2007, the U.S. Department of Energy Hydropower and Hydrokinetic Office (H2O) has invested in marine energy research and development to advance the technical readiness and increase the affordability of tidal energy and other marine energy technologies. In 2023, H2O released the largest tidal funding opportunity to date: $45 million for tidal energy advancement.

In accordance with the Government Performance and Results Act (GPRA), H2O annually assesses marine energy technology development resulting from government-funded research and development programs and strategy. For GPRA reporting, H2O uses the levelized cost of energy (LCOE)—which represents the total system cost per unit of energy produced—to measure the progression of marine energy technology development, assess the impact of their research and development programs, and identify future research priorities. To support H2O's GPRA reporting requirements and inform future strategy, the National Laboratory of the Rockies conducted a tidal energy LCOE expert elicitation study to estimate present and future LCOE. This report describes the motivation and background for the elicitation study, the methodology used to conduct the study, and the study results. It also provides future recommendations for accelerated tidal energy LCOE reduction based on feedback from study participants.

Based on responses provided by study participants, the average LCOE for the year 2022 is $0.36 per kilowatt-hour (kWh) ± $0.11/kWh. On average, the study participants estimate that LCOE may reach $0.20/kWh by 2036 ± 6 years for the conservative case and 2033 ± 6 years for the optimistic case. The average LCOE estimates for 2050 under the conservative and optimistic scenarios are $0.17/kWh ± $0.08/kWh and $0.11/kWh ± $0.06/kWh, respectively. The participating experts identified the following cost categories as being the leading cost contributors to LCOE: (1) power take-off system, (2) maintenance, (3) structural assembly, (4) operation, (5) mooring, foundation, and substructure. The following are other key takeaways from the study:

- There is no single action to reduce tidal energy LCOE. Accelerated LCOE reduction depends on the combination of economies of scale, economies of volume, learning by doing, and innovation through research and development.
- The experts highlighted the mutually beneficial relationship between cumulative installed capacity and cost reduction, where more deployments lead to more cost reductions through learning by doing and economies of volume. Additionally, study participants emphasized the critical need for financial and revenue support to launch the advantageous cycle of deployments that will lead to cost reductions and drive future deployments.
- There is a need for a streamlined consenting process that enables faster and easier approval of tidal energy projects.
- Risk is a significant barrier to early tidal energy projects. It contributes to high insurance cost and high cost of capital and makes investors and project developers reluctant to support tidal energy deployments. The influence of risk highlights the importance of receiving financial and revenue support for projects to improve investor confidence, as

well as completing thorough risk assessments prior to deployments to avoid preventable accidents that impact the demonstration of operational hours (and ideally high availability, which is defined as operational time divided by the total time deployed).

- Ongoing financial and revenue support[1] throughout early deployments of single-unit and multi-unit array demonstrations is essential for gaining cumulative installed capacity, which will drive LCOE reductions and boost investor confidence. This support will help tidal energy technologies overcome initial deployment barriers associated with high costs and risks so they can accumulate operational hours to prove technical performance and reliability, thereby de-risking technologies and offshore operations with successful deployments.

[1] Financial support includes mechanisms like grants, loans, and tax credits, and revenue support includes mechanisms such as feed-in tariffs that provide funding based on energy generation.

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Introduction

The United States has invested in marine energy research and development (R&D) since the Energy Independence and Security Act of 2007 was enacted to promote greater energy independence and improve energy security (Congress.gov 2007). Marine energy (also known as marine and hydrokinetic energy, marine renewable energy, or ocean energy) includes a suite of technologies that harness energy from ocean waves, tides, currents, and other water-based resources.[2]

The U.S. Department of Energy's (DOE's) Hydropower and Hydrokinetic Office (H2O)[3] administers R&D programs to advance marine energy technologies. On an annual basis they must report on the performance of their programmatic goals and strategies as part of the Government Performance and Results Act (GPRA) of 1993. For the purpose of GPRA reporting, the main metric used by H2O to assess technology development as a result of R&D programs is the levelized cost of energy (LCOE), which represents the total system cost per unit of electricity generated. LCOE is estimated using capital expenditures (CapEx), operational expenditures (OpEx), and annual energy production over the project lifetime. LCOE is a common metric used to measure the affordability of all types of energy generation systems. However, for the purpose of GPRA reporting, LCOE analysis is one method used to evaluate the progression of a technology, where the step change in LCOE is of greater interest than the absolute value. At present, no marine energy technology has reached cost parity with other renewable energy technologies like wind and solar; hence, LCOE reduction is a major objective of marine energy R&D. Tidal energy, which is the focus of this report, is typically considered to be more technologically advanced and closer to commercialization than other marine energy technologies such as wave energy (OES 2023).

The purpose of this work is to estimate present and future LCOE for tidal energy technologies using an expert elicitation. This work builds on the wave energy LCOE expert elicitation completed in 2022 (Baca 2022) using the same data collection methods and similar participant engagement strategy. Expert elicitation studies are conducted to develop a collective understanding of a technology area and to gain insight on possible future trends related to technology cost and performance as well as other research interests. They are structured to collect quantitative and qualitative data from developers, engineers, and other researchers who have expert knowledge about the technology of interest (Verdolini et al. 2018) and are especially helpful for technologies that have limited publicly available data related to actual commercial deployments. Study participants are typically engaged through various communication modes—including in person or virtual meetings and email—and some interaction between participants, such as group discussions, may occur. The fundamental framework for this elicitation study and the previous wave energy LCOE elicitation (Baca 2022) was adapted from wind energy technology elicitation studies conducted by Wiser et al. (2016, 2021). Some known challenges with conducting expert elicitation studies include:

[2] Although not clearly represented in the name, some marine energy technologies utilize inland resources such as free-flowing water in rivers, streams, and man-made canals.
[3] https://www.energy.gov/cmei/water/hydropower-and-hydrokinetic-office

- Identifying a highly qualified and diverse pool of experts
- Gaining the participation of those experts
- Minimizing (or managing) the bias of the participants and the researchers conducting the study
- Identifying inaccuracies in the results due to the underestimation of, or overconfidence in, the technological advancement rates assumed by the experts (Wiser et al. 2021; Verdolini et al. 2018).

Despite these challenges, elicitation studies have the potential to reveal unique insights and quantitative information from experts for data-limited technologies. Additionally, study results may supplement other approaches to estimate current and future LCOE values. The most common alternative methods for estimating LCOE are briefly discussed herein.

Two alternative methods for estimating LCOE include bottom-up or top-down techno-economic analysis. For estimating present-day system costs, bottom-up techno-economic analysis is the most detailed method that accounts for all project costs over the project lifetime, but it is challenged by the requirement for detailed cost and performance data, both of which come with varying uncertainty that propagates to the results. This method carries higher uncertainty for early-stage technologies, as the analysis is largely informed by data from cost and performance models in the absence of actual deployment data. Bottom-up LCOE estimates become more certain as technologies become more mature and data are collected from deployments. However, pre-deployment LCOE estimates always carry some uncertainty, as cost and performance will vary depending on the site location and other factors. Alternatively, top-down (or "reverse") LCOE analysis estimates the LCOE of a potential market (i.e., LCOE for diesel generators in remote communities or market energy rate) and then uses the LCOE as an input to calculate a range of project cost targets that need to be achieved for a technology to become cost competitive with existing energy generation methods employed by the market (Têtu and Chozas 2021).

Learning curves are another method to estimate LCOE. They can be applied to historical or modeled LCOE data to quantify potential LCOE reductions achieved through serial production or cumulative installed capacity and then used to make future LCOE projections. This method extrapolates future trends based on observed learning rates for other technologies that have accumulated installed capacity with measurable reductions in LCOE. Learning rates are typically applied at the component level, with novel components having higher discount factors than off-the-shelf components. However, this approach also faces several challenges: (1) future LCOE values depend on the initial LCOE value being discounted (which has uncertainty), (2) the LCOE projections are sensitive to the initial installed capacity assumed (since, mathematically, learning curves rely on the doubling of installed capacity), (3) it is difficult to accurately assign component discount factors (to strike a balance between optimism and conservatism), and (4) this approach does not explicitly model other LCOE reduction effects from R&D or economies of scale (Meng et al. 2021).

All these analysis methods come with both benefits and drawbacks. However, research has shown that the bottom-up LCOE analysis and learning curve methods tend to underestimate technological advancements, whereas expert elicitation studies have more narrow uncertainty ranges (Meng et al. 2021). In this work, the expert elicitation study is intended to complement the other methods discussed, and the results may be used to reinforce or validate the assumptions of those methods. The results of this work will establish the U.S. tidal energy LCOE baseline, which will be used to inform H2O’s GPRA reporting requirements and shape future tidal energy programmatic R&D strategies and initiatives.

1 Background

The marine energy industry is a rapidly expanding part of the larger renewable energy industry and has the potential to enhance the resilience and reliability of energy systems in the United States. While the marine energy industry comprises a range of maritime and ocean resources, the tidal energy industry (also referred to as tidal stream and defined as energy from tidal currents, excluding tidal barrages) is generally considered to be the most technically advanced and the closest to commercialization. A summary of the state of the tidal energy industry and the various economic support mechanisms implemented globally is provided in Sections 2.1 and 2.2 and is followed by a discussion of the current and future estimates for the LCOE of tidal energy as reported in recent literature (Section 2.3).

1.1 State of the Tidal Energy Industry

Tidal energy, derived from the existing kinetic energy in tidal streams, can be a beneficial component of a reliable energy system. The following are some advantages of tidal energy:

- Predictability: Because tides are mainly driven by the positions of the moon and sun, they are highly predictable years in advance, unlike many other renewable energy resources.
- Proximity to load: Strong tidal currents typically occur close to shore, corresponding with high U.S. population density along coasts, which reduces the need for transmission over long distances.
- Lower potential for co-use conflicts: Sites with strong tidal currents are often in areas that other maritime stakeholders avoid, reducing the likelihood of user conflicts.

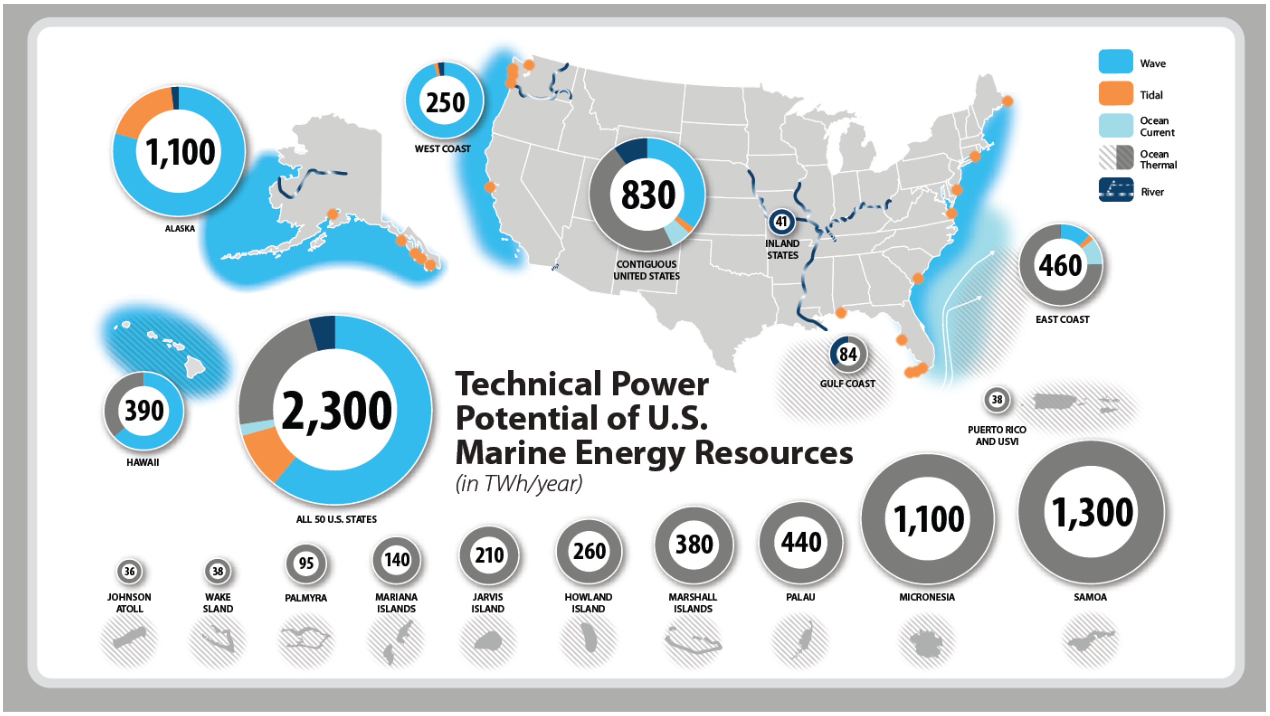
Conversely, there are a number of challenges associated with tidal energy, including:

- Reducing the cost of tidal energy to compete with existing energy generation technologies
- Difficulties associated with deploying, operating, and maintaining machinery in high-energy, saltwater environments
- Mitigating the potential impact on marine life and marine ecosystems
- Managing the equitable use of the marine environment with a broad range of impacted stakeholders.

International efforts are ongoing to address these challenges in a transparent and rigorous manner (Huckerby et al. 2016).

To understand the potential for tidal energy generation, work has been done globally to estimate the available tidal energy resource. To support a common understanding of the global resource, the International Electrotechnical Commission (IEC) Technical Committee 114, "Marine energy - Wave, tidal and other water current converters," developed publicly available vocabulary for resource assessment. Specifically, *theoretical resource* is defined as the "energy available in the resource," *technical resource* is defined as the "proportion of the theoretical resource that can be captured using existing technology options without consideration of external constraints," and *practical resource* is defined as the "proportion of the technical resource that is available after consideration of external constraints" (IEC 2022). The International Energy Agency's Technology Collaboration Programme on Ocean Energy Systems (IEA-OES) suggested a global theoretical resource of 1,200 terawatt-hours per year (TWh/year) (Huckerby et al. 2016);

however, this estimate was based on an analysis conducted in 2010. In the United States, a study conducted by the National Laboratory of the Rockies in 2021 estimated the technical resource for tidal energy in the United States at 220 TWh/year, equivalent to roughly 5% of the total electricity generation (Figure 1; Kilcher, Fogarty, and Lawson 2021).



U.S. States[a]	Technical Resource (TWh/yr)[b]	Potential Number of Homes Powered[c]	Resource as a Percent of U.S. Electricity Generation (%)[e]
Wave (to EEZ)	1,400	130,000,000	34
Tidal	220	21,000,000	5.4
Ocean Current	49	4,600,000	1.2
Ocean Thermal	540	51,000,000	13
River	99	9,300,000	2.4
Total	**2,300**	**220,000,000**	**57**

[a]All values are listed to two significant figures; therefore, totals shown may not equal the sum of values.
[b]Detailed methodologies for estimating Technical Resource are provided in Section 2 of the report.
[c]Based on avg. monthly household electricity use of 877 kWh/month—or 10,649 kWh in 2019.
[e]Percent based on all 50 U.S. states' electricity generation (4,126.7 TWh) in 2019.

East Coast[a]	Technical Resource (TWh/yr)[b]	Potential Number of Homes Powered[c]	Resource as a Percent of Regional Electricity Generation (%)[d]	Resource as a Percent of U.S. Electricity Generation (%)[e]
Wave (to EEZ)	55	5,200,000	6.0	1.3
Tidal	10	950,000	1.1	0.24
Ocean Current	49	4,600,000	5.3	1.2
Ocean Thermal	340	32,000,000	37	8.3
River	0.67	63,000	0.07	0.02
Total	**460**	**43,000,000**	**49**	**11**

[d]Percent based on 924.5 TWh of the East Coast's electricity generation produced in 2019. (ME to FL with 1/2 of FL's generation.)

Figure 1. Technical power potential of U.S. tidal and other energy resources.

Image from Kilcher, Fogarty, and Lawson (2021)

Based on global, regional, and national tidal energy resource assessments, a range of tidal energy deployment targets have been established: The European Union set a goal for 100 megawatts (MW) of installed marine energy (wave and tidal) by 2025, 1 gigawatt (GW) by 2030, and 100 GW by 2050 (Directorate-General for Maritime Affairs and Fisheries 2024). Ocean Energy Europe published "Last Stop to 2025" with an action plan to achieve these targets (Collombet and Cagney 2022). In 2024, the U.K. Marine Energy Council encouraged the U.K. government to set a target of 1 GW of tidal energy by 2035 (U.K. Marine Energy Council 2024). In the United States, the National Hydropower Association Marine Energy Council (NHA-MEC) established deployment targets for marine energy (all resources) of 50 MW by 2025, 500 MW by 2030, and 1 GW by 2035 (NHA-MEC 2021). The IEA-OES published a report outlining a roadmap to the development of 300 GW of marine energy by 2050 (OES 2023).

To achieve these deployment targets, R&D activities are ongoing at universities, at national laboratories, at technology development companies, and across the supply chain. Testing infrastructure is growing at lab scale and in the open water, and in-water projects, both grid-connected and off-grid, are under development (in various stages) globally. The 2023 IEA-OES annual report (OES 2024), Ocean Energy Europe's 2023 Stats & Trends report (Ocean Energy Europe 2024), and Marine Energy Wales' 2024 State of the Sector report (Marine Energy Wales 2024), among other publications, summarize international activities.

In addition to technical advancements, changes to regional, national, and local legislation have supported the development of the tidal energy industry. In the United States, California Senate Bill SB-605, known as the "Wave and Tidal Energy Bill," was signed into law by Governor Gavin Newsom in October 2023. The bill requires the California Energy Commission and the Ocean Protection Council to commence a comprehensive, collaborative study to evaluate the feasibility and benefits of using wave energy and tidal energy, as specified. To meet Bill SB-605 requirements, a report titled *Sea Space Analysis for Wave and Tidal Energy* (Lee et al. 2025) was issued in July 2025; however, an overarching final report with recommendations is pending publication by the California Energy Commission. Additional examples of legislative activities globally can be found in the IEA-OES annual report (OES 2024).

1.2 Economic Support for Tidal Energy

A range of economic incentives and support mechanisms are in use by various countries to accelerate marine energy commercialization by encouraging investment in technology developers and projects. The range of measures is quite broad, from direct revenue support on energy generation to grants and loans across the development path to tax credits, among others. In many cases, countries use a portfolio of mechanisms to provide economic support to bring tidal energy technologies and projects to the marketplace.

In the United Kingdom, a mechanism called a contract for difference (CfD) has been available for tidal energy projects, with a dedicated budget—or a ringfence—since 2022. In 2024, the tidal energy ringfence was £10 million ($12.8 million in 2024 USD). As described by the U.K. government, "a Contract for Difference (CfD) is a private law contract between a low carbon electricity generator and the Low Carbon Contracts Company (LCCC), a government-owned company" (Department for Energy Security and Net Zero 2016). The contracts are awarded based on a competitive bidding process known as an allocation round (AR). AR1 was initiated in 2014–2015; however, beginning with AR4 in 2021–2022 and continuing with AR5 in 2023 and AR6 in 2024, a specific call out was made for tidal energy projects. In each AR, an administrative strike price is set that represents the maximum allowable price for the energy generated from tidal energy projects. This administrative strike price was set at £211 ($334) per megawatt-hour (MWh) in AR4, £202/MWh ($320/MWh) in AR5, and £261/MWh ($414/MWh) in AR6. These prices are based on 2012 currency (including the USD conversions) and will be adjusted for inflation at the time of energy delivery. All these values are significantly above the market value of electricity in the United Kingdom. Once an AR is opened, project developers submit applications to qualify, and once all qualifying applicants have been accepted, the sealed bidding process begins. Based on the bids received, a final clearing price is determined, and capacity awards (in megawatts) are made to the successful applicants. Table 1 summarizes the results of the previous ARs for tidal energy:

Table 1. Summary of Contract for Difference Allocations to U.K. Tidal Projects

Allocation Round	Administrative Strike Price (2012 Currency)	Final Clearing Price (2012 Currency)	Project Name	Allocated Capacity (MW)	Delivery Date
AR4 (held 2021–2022)	£211/MWh	£178.54/MWh	Eday	7.20	2026–2027
			MeyGen	28.00	2026–2027
			Morlais	5.62	2025–2026
			AR4 Total	***40.82***	
AR5 (held in 2023)	£202/MWh	£198/MWh	Eday	7.20	2027–2028
			MeyGen	21.94	2027–2028
			Morlais	23.90	2026–2027 and 2027–2028
			AR5 Total	***53.04***	
AR6 (held in 2024)	£261/MWh	£172/MWh	SEASTAR	4.00	2028–2029
			OCEANSTAR	2.00	2028–2029
			EMEC Berth 1 Extension	3.00	2028–2029
			MeyGen	9.00	2028–2029
			Morlais	10.00	2027–2028
			AR6 Total	***28.00***	
AR7a (held in 2025–2026)	£266/MWh	£190.19/MWh	Eday	2.40	2029–2030
			Morlais	18.50	2028–2029 and 2029–2030
			AR7a Total	***20.90***	
Total, AR4–AR7a				**142.76**	

In summary, to date, the CfD mechanism in the United Kingdom has allocated 142.76 MW of tidal energy projects in U.K. waters, with delivery dates beginning in 2025–2026 through 2029–2030. Of the total allocation, both the MeyGen and Morlais projects have been allocated nearly 60 MW each. The total allocation represents just over 10% of the deployment target, as recommended by the U.K. Marine Energy Council. This revenue stream, with guaranteed prices above market rate, is critical for technology and project developers looking to raise development and project funding. The results of AR6 and AR7a added an additional capacity of 28 MW and

20.9 MW, respectively. It is expected that the CfD mechanism will be a key driver in the deployment of utility-scale tidal energy projects in the United Kingdom in the coming years.

It is also important to note that while the administrative strike price went down from AR4 to AR5, the final clearing price went up. It is likely that tidal energy developers were overly aggressive in AR4 bidding and reconsidered this strategy when bidding into AR5. Further, it should be noted that while the AR6 administrative strike price was raised significantly, the final clearing price decreased significantly relative to AR5. However, in AR7a, the final clearing price returned to near AR5 levels. It is possible that tidal developers are beginning to realize cost reductions and that by the 2029–2030 delivery date they can reach profitability at these lower cost targets. On the other hand, it is also possible that tidal developers bid low in AR6 to ensure a successful CfD, regardless of the profitability at lower final clearing prices, as any revenue is better than none. When evaluating this idea against AR7a, it seems likely that developers recalibrated their bids to ensure that such a low final clearing price was not realized in AR7a. The future results of AR8 and beyond, as well as the ultimate delivery of the tidal projects with AR results to date, will be important indicators of the health and trajectory of the tidal energy sector.

Drawing on the U.K. model for CfD, both France and Italy have recently announced similar revenue mechanisms for tidal energy projects. In June 2024, it was announced that "Italy plans to introduce a €35.5 billion ($38.4 billion in 2024 USD) scheme to support renewable electricity production until 31 December 2028, financed by a levy on consumers' electricity bills, and award CfDs for up to 4,590 MW of projects," including tidal energy projects (Maksumic 2024). Similarly, the French government announced significant funding and dedicated revenue support for a 17.5-MW pilot project at the Raz Blanchard in the English Channel (Power Technology Staff 2023).

In Canada, Nova Scotia's government has taken a different approach to revenue support; in 2013 they offered a feed-in tariff of C$530/MWh ($515/MWh in 2013 USD) managed and adjusted by the Nova Scotia Utility Review Board for developmental tidal energy projects (Nova Scotia Utility Review Board 2013; Gardner et al. 2015). Three projects at the Fundy Ocean Research Centre for Energy have approval for this feed-in tariff (OES n.d.).

In the United States, the predominant economic support at the federal level is in the form of production tax credits and investment tax credits. As part of the Inflation Reduction Act of 2022, several tax credits were included for marine energy projects. These credits include a production tax credit, a clean energy production tax credit, an investment tax credit, a clean energy investment tax credit, and other cross-cutting provisions (National Hydropower Association 2024), though the details of these and other energy tax credits are evolving as a result of recent congressional action. Information on incentives offered by federal and state governments can be found in the Database of State Incentives for Renewables & Efficiency (https://dsireusa.org/).

At the state and local levels, a range of revenue support mechanisms are available. In New York City and Westchester, the Consolidated Edison Company of New York Inc. offers additional revenue support to specific electric distributed generation equipment, including tidal energy. This revenue support, known as a "value stack service," is available for tidal generating equipment with a rated capacity less than 5 MW. Included in this value stack service are the base energy value, an installed capacity value, an environmental value, and a demand reduction value. The demand reduction value, however, is only applicable at select hours during non-holiday weekdays.

In Maine, the Net Energy Billing program includes tidal energy generation and provides a tariff for generation, determined annually by the Maine Public Utilities Commission (n.d.), that depends on the customer class and the utility service territory.

1.3 Tidal Energy LCOE

1.3.1 LCOE Definition

As mentioned in Section 1, the LCOE represents the total system cost per unit of electricity generated based on an assumed project life, project financing parameters, and annual average performance values and is a standardized metric used to evaluate the cost and performance of energy generation technologies. In the simplest terms, the LCOE represents the rate at which one must sell electricity over a given period of time to break even on an investment. LCOE has multiple equation variants, all of which yield similar results. The LCOE fixed charge rate method is defined by Equation (1):

$$LCOE = \frac{(CapEx \times FCR) + OpEx}{AEP} \tag{1}$$

where:

- *CapEx* is measured in dollars
- *FCR* is the fixed charge rate as a percentage
- *OpEx* is measured in dollars per year
- *AEP* is the annual energy production in kilowatt-hours.

LCOE is measured in dollars per kilowatt-hour ($/kWh). The fixed charge rate annualizes (or discounts) the project’s lifetime CapEx and has baked-in assumptions regarding the project’s economic life, taxes, and discount rate. Typically, a fixed charge rate value is assumed, but the assumed value is based on a calculation using Equations 2 and 3:

$$FCR = \frac{r}{1 - \frac{1}{(1-r)^n}} \times \frac{1-D}{1-\tau} \tag{2}$$

where:

- r is real discount rate (i.e., the weighted average cost of capital)
- D is the present value of depreciation tax shield represented by Equation 3
- n is the project economic life
- τ is the composite federal-state tax rate.

$$D = \tau \times \sum_{t=1}^{t=6} \frac{MACRS_t}{(1+r)^t \times (1+i)^t} \tag{3}$$

where:

- τ is the composite federal-state tax rate
- t is time
- $MACRS_t$ is the modified accelerated cost recovery system 5-year depreciation schedule shown in Table 2
- r is real discount rate (i.e., the weighted average cost of capital)
- i is the inflation rate.

Table 2: MACRS 5-Year Depreciation Schedule

Year	5-Year MACRS Depreciation Schedule
1	0.2
2	0.32
3	0.192
4	0.1152
5	0.1152
6	0.0576

For more information about fixed charge rate and LCOE, visit: https://openei.org/wiki/PRIMRE/Telesto/Economics and https://openei.org/wiki/PRIMRE/Telesto/Metrics/Levelized_Cost_of_Energy.

1.3.2 Tidal Energy LCOE Data From Literature and Public Sources

This study included a literature review focused on present and future values of tidal energy LCOE with two main objectives:

1. To gather present and future estimates of tidal energy LCOE as presented in the literature (or other publicly available sources) to share with study participants in an effort to manage bias by ensuring that all study participants were aware of this information.
2. To compare published tidal energy LCOE data with the results of the tidal energy LCOE expert elicitation.

The collected tidal energy LCOE data are compiled in Figure 2, which was shared with participants at the time of the study. Note that CfD AR7 is not included in Figure 2, as this round was not yet announced at the time of the study. The data come from many sources (Carlsson et al. 2014; Frost 2022; ORE Catapult 2018; Jenne, Yu, and Neary 2015; Magagna, Monfardini, and Uihlein 2016; European Commission 2016; IRENA 2020; Magagna 2019; Milne 2020; Tapoglou et al. 2022; OES 2023; Proteus Marine Renewables 2024) and include estimates published from 2013 to 2023. All collected data were converted to 2022 U.S. dollars. More information about individual sources is provided in the next section.

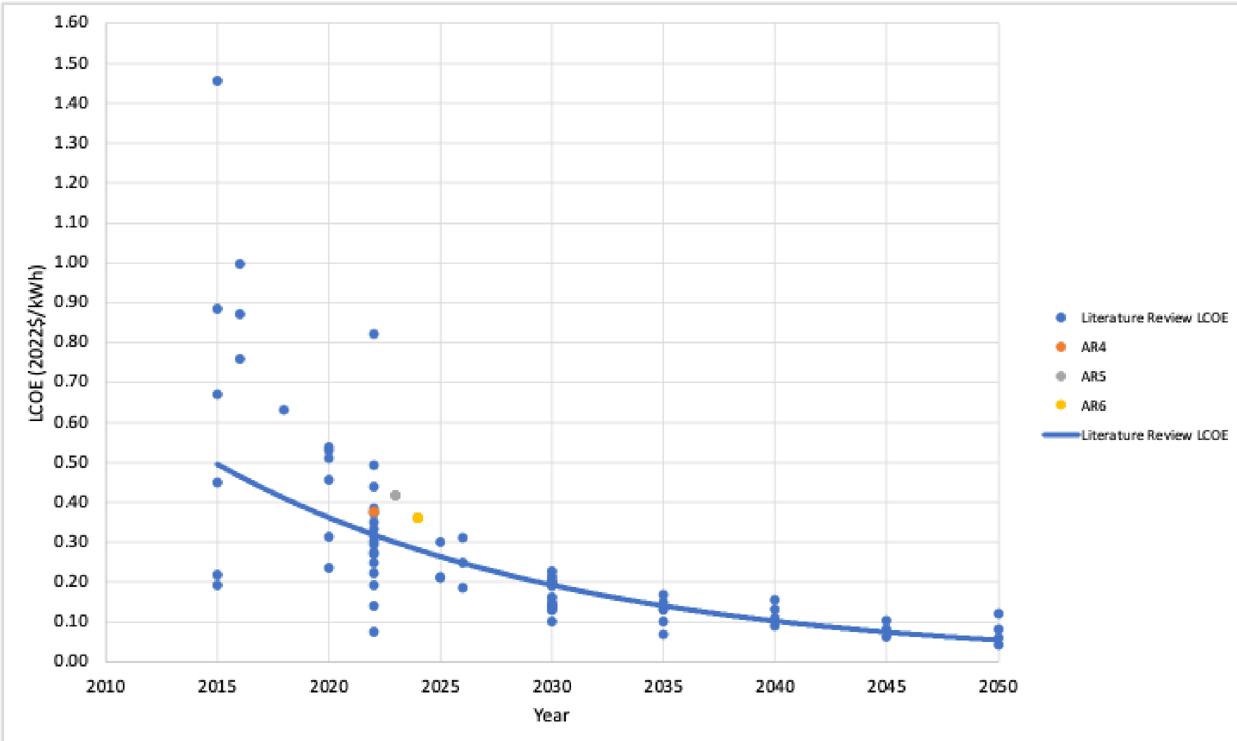


Figure 2. LCOE estimates as presented in the literature (blue dots) and from U.K. contracts for difference administrative strike prices (orange, gray, yellow dots), converted to 2022 U.S. dollars. The blue line is a best-fit curve. AR7 is excluded as it was not yet announced during the study.

Data sources: (Carlsson et al. 2014; Frost 2022; ORE Catapult 2018; Jenne, Yu, and Neary 2015; Magagna, Monfardini, and Uihlein 2016; European Commission 2016; IRENA 2020; Magagna 2019; Milne 2020; Tapoglou et al. 2022; OES 2023; Proteus Marine Renewables 2024)

1.3.3 Tidal Energy LCOE History

This section provides an overview of key references from the literature review and data shown in Figure 2. This overview is not a comprehensive tidal energy LCOE history, as the literature review focused on publications from the last decade. In 2013, the Strategic Energy Technology Plan (SET-Plan) presented a strategy to accelerate the European Union's energy system transformation and provided future projections for tidal energy LCOE, as shown in Table 3 (Carlsson et al. 2014).

Table 3. Tidal Energy LCOE SET-Plan Projections for 2020–2050

Data from Carlsson et al. (2014)

LCOE	2020	2030	2040	2050
€2013/MWh	180	130	90	70
$2022/MWh	300	220	150	120

The early SET-Plan projections presented in the roadmap are not accompanied by present-day baseline estimates. Soon after, the DOE-funded Reference Model Project estimated that Reference Model 1, a hypothetical 1-MW-rated tidal turbine (based on the SeaGen technology from Marine Current Turbines), had an LCOE of $170/MWh ($210/MWh in 2022 USD) for a 100-unit array (Neary et al. 2014; Jenne, Yu, and Neary 2015). In 2016, European Commission services, European Union member states, and other SET-Plan stakeholders agreed to set ocean energy cost targets. The SET-Plan targets (as shown in the SET-Plan declaration of intent) for tidal energy LCOE in 2025 and 2030 were €150/MWh and €100/MWh, respectively (European Commission 2016). In addition to the LCOE targets presented in the SET-Plan, availability targets were set as well. Table 4 summarizes the LCOE and availability SET-Plan targets as presented in the declaration of intent.

Table 4. The SET-Plan Targets for Tidal Energy

Data from European Commission (2016)

Target Metrics	2025	2030	2040
LCOE (€2016/MWh)	150	100	-
LCOE ($2022/MWh)	200	130	-
Availability (%)	80	90	95

The SET-Plan LCOE targets did not include present-day LCOE estimates; however, the Joint Research Centre's 2016 report stated that present-day (for the year the SET-Plan targets were set) tidal energy LCOE ranged between €540/MWh and €710/MWh ($729/MWh and $958/MWh, respectively, in 2022 USD) for an average resource and estimated a reference value of about €620/kWh ($837/MWh in 2022 USD) (Magagna, Monfardini, and Uihlein 2016). The SET-Plan targets and all projected future LCOE values typically assume that targets will be achieved through large deployment volumes (contributing to cumulative installed capacity), economies of scale, learning by doing, and continued innovation through R&D. The SET-Plan targets were officially implemented in 2018 and updated again in 2021. The 2021 SET-Plan target update included installed capacity targets of 100 MW by 2025 and 1 GW by 2030 for wave and tidal energy. Some of the previously mentioned LCOE estimates are more than a decade old, but they are highlighted here because they are frequently referenced and provide historical context to tidal energy LCOE. Additionally, these targets likely motivated U.K. government economic support (like the CfD mechanism) to increase tidal energy deployments. It is worth noting that there is no U.S. equivalent for the SET-Plan, and the United States has no formal future LCOE targets for tidal energy.

Other notable sources include the 2018 ORE Catapult report, which provides a current-day estimate (in 2012 currency to match the CfD strike prices) for tidal energy LCOE of £300/MWh ($606/MWh in 2022 USD) and projected future LCOE values tied to installed capacity rather than specific years. The 2018 ORE Catapult report concluded that tidal energy LCOE has the potential to reach £150/MWh ($303/MWh in 2022 USD) with 100 MW of installed capacity, decreasing to £90/MWh ($182/MWh in 2022 USD) with 1 GW of installed capacity, and dropping further to £80/MWh ($162/MWh in 2022 USD) with 2 GW of installed capacity (ORE Catapult 2018). The key findings suggested that LCOE reductions would be driven by economies of scale, learning by doing, maturation of the market and supply chain, a reduced cost of capital, and technology innovations leading to increased reliability and availability.

In 2022, the Tidal Stream Industry Energiser (TIGER) project published a study designed to be an update to the 2018 ORE Catapult report and to quantify tidal energy cost reduction trends (Frost 2022). The TIGER study gives updated LCOE trajectories for the tidal energy industry, as shown in Table 5.

Table 5. Tidal Stream Industry Energiser Project LCOE and Capacity Targets

Data from Frost (2022) reported in 2012 British pounds to align with CfD strike prices

Target Metrics	2022	2026	2030	2035
LCOE (£2012/MWh)	259 ± 30	193 ± 48	116 ± 38	78 ± 25
LCOE ($2022/MWh)	523 ± 61	390 ± 97	234 ± 77	158± 51
Assumed Global Installed Capacity (MW)	-	-	730	2,600

The future LCOE estimates provided by TIGER (Frost 2022) assume a global cumulative installed tidal energy capacity of 730 MW and 2,600 MW by 2030 and 2035, respectively. The study concluded that the cost reduction mechanisms are driven by economies of scale (larger rotor diameter and rated power), economies of volume (larger array sizes), innovations in technology components, reductions in cost of capital, and learning by doing.

More recently, two tidal energy developers openly shared LCOE targets for their technologies. In 2020, Orbital Marine Power stated a target LCOE of under £200/MWh for their 2-MW O2 device ($290/MWh in 2022 USD) (Milne 2020). In 2024, Proteus Marine Renewables shared the results of a third-party verification study of their LCOE reduction forecast based on the horizontal-axis AR3000 tidal energy system and the Normandie Hydroliennes 12-MW pilot tidal array project, referred to as NH1. The study concluded that the LCOE targets for the technology were reasonable and that the LCOE target of €150/MWh ($156/MWh in 2022 USD) for a 200-MW array was achievable for the next project phase (NH2) (Proteus Marine Renewables 2024).

Many other reports were reviewed as part of this literature review but are not included in this section because of the literature citing information from targets or studies previously discussed or because the assumptions regarding estimates were unclear and therefore not included in the dataset. As illustrated in the LCOE data discussed in this section, summarizing LCOE data from multiple sources can be confusing because of the different currencies and currency years used. In the literature review, we found that LCOE data are repeatedly reused (unchanged) for many years in literature without providing clarification on the currency year assumed or updating LCOE values for inflation. In this section we did our best to trace LCOE estimates back to the original source and tried not to duplicate data copied in subsequent (newer) reports. All values in this report are converted to USD using the publication year or original assumed currency year; then, once values are in USD, they are updated for inflation to 2022 USD. All CfD strike prices or feed-in tariffs are intentionally kept at their assumed currency year (unless included in plots), as they are intended to be updated at time of delivery (see discussion in Section 2.2).

2 Methodology

The tidal energy LCOE elicitation effort began in 2022 following the wave energy LCOE elicitation completed in that year (Baca et al. 2022). The methodology for the tidal energy LCOE elicitation mirrored the method used in the wave energy LCOE elicitation with a few minor exceptions (discussed herein). The study methodology comprised six main steps:

1. Conduct a literature review.
2. Develop a list of experts to invite to participate in the study.
3. Contact experts to request participation in the study.
4. Hold workshops to provide an overview of the study objectives and to describe the data collection method with study participants.
5. Collect completed feedback forms from study participants.
6. Carry out a data analysis of the results.

To prepare for engaging with tidal energy experts, a literature review was conducted that primarily focused on publications reporting current and future values of tidal energy LCOE, as discussed in Section 2.3.3. Publications that focused on tidal energy road mapping, strategy, or technology development were also of interest. The objective of the literature review was to assess the state of the tidal energy industry—regarding technology development and cost of energy—to prepare the researchers carrying out the study and to inform study participants of key findings. A summary of the literature review was shared with study participants to manage bias by ensuring they were aware of present-day LCOE estimates and future LCOE trajectories as presented in the literature.

The next step involved developing a list of tidal energy experts to invite to participate in the expert elicitation. Those identified included tidal technology developers, researchers from national laboratories, and experts from academia, consulting firms, and certification bodies. Participants were contacted via email to request participation in the study. Those who agreed to participate were invited to attend a webinar to learn more about the study objectives and how information would be collected. Throughout the duration of the study, three modes of communication were used to engage with participants—email, webinars, and virtual meetings. Qualitative and quantitative data were collected from participants with a guided response form and through webinar discussions.

2.1 Feedback Form

The guided response form used to obtain participant feedback was previously developed and used for the wave energy LCOE expert elicitation study. The response form is an Excel workbook with eight spreadsheets—five dedicated to guided responses and three presenting instructions and definitions of the cost breakdown structure being used in the questioning. The overall goal of the response form is to obtain expert opinion on the present-day and future values of LCOE, the expected cost breakdown as a percentage of the LCOE contribution, and details about the theoretical tidal energy project that the LCOE and cost estimates describe. The response form includes conservative and optimistic scenarios that enable respondents to provide a range of values for future estimates and space to provide general qualitative feedback.

The response form prompted users to estimate the LCOE in 2022 (the baseline), the year that the tidal energy LCOE would reach $0.20/kWh for conservative and optimistic scenarios, and the LCOE for 2050 for conservative and optimistic scenarios. The assumptions for the baseline 2022 scenario were as follows:

- LCOE is based on a 100-MW array.
- Annual energy production is based on 8,760 hours per year, the 100-MW array, and the capacity factor (CF) estimate provided by the respondent.
- The fixed charge rate is 10.8%, based on the real discount rate of 7% and a 20-year project life.
- The hypothetical array may assume any tidal energy type and that some project-specific economies of scale are achieved but that industry-wide economies of scale or learning have not yet been realized.

For the future conservative scenarios, the assumptions were the same, except that respondents could make their own assumptions about economies of scale and learning rates. For future optimistic scenarios, the assumptions differed by assuming a fixed charge rate of 8.95%, which represents a real discount rate of 6% and a project life of 25 years. Additionally, respondents could make their own assumptions regarding economies of scale and learning rates for future optimistic scenarios.

In all cases, participants were asked to provide estimates for the percentage contribution of LCOE for CapEx and OpEx (i.e., the percentage split of LCOE for CapEx and OpEx). Then, using the CapEx and OpEx LCOE percentage contribution estimates, respondents were asked to estimate the percentage of LCOE contribution for the associated cost categories of CapEx and OpEx, as shown in Figure 3, which uses a simplified version of the marine energy cost breakdown structure.

Step 6)	Using the input from Step 3, enter the percent LCOE contribution of each CapEx	
		LCOE % Contribution
	CapEx % LCOE Contribution from step 2	70%
	Marine Energy Converter	
	a. Structural Assembly	10%
	b. Power Take-Off System	30%
	c. Mooring, Foundation, and Sub-structure	10%
	Balance of System	
	a. Development (Includes permitting and regulatory fees)	2%
	b. Engineering and Management	2%
	c. Electrical Infrastructure (Includes Cables/Substation)	5%
	d. Plant Commissioning	1%
	e. Site Access, Port & Staging	1%
	f. Assembly and Installation	5%
	g. Other Infrastructure	1%
	Financial	3%
Step 7)	Check Total	70%

Step 8)	Using the result from Step 4, enter the LCOE contribution of each OpEx Category	
		LCOE % Contribution
	OpEx % LCOE Contribution from step 4	30%
	Operation (Includes annual leases and	15%
	Maintenance	15%
Step 9)	Check Total	30%

Figure 3. Example of user input to the LCOE percentage contribution in the feedback form

Additionally, respondents were asked to estimate the CF and total cumulative installed capacity for all cases. Lastly, participants were asked to answer a series of questions that provided supplemental context to responses. The questions were designed to elicit a mixture of quantitative and qualitative responses. The questions were:

1. What is the device or technology type that you envision for the hypothetical 100-MW array?
2. What is your assumed rated power, in megawatts, of a single device in the hypothetical 100-MW array?
3. What is your assumed water depth, in meters, for the hypothetical 100-MW array?
4. What is your assumed distance to shore, in kilometers, for the hypothetical 100-MW array?
5. What is the total cumulative installed capacity for the tidal and ocean current energy industry when this hypothetical array is installed?
6. How many open-water demonstrations or prototypes have been deployed prior to this hypothetical array?

2.2 Webinars

For this study, three webinars were held with the following objectives:

- To provide an overview of study objectives
- To discuss how information would be collected and receive feedback on the response form
- To have a group discussion on the tidal energy landscape now and in the future, focusing on LCOE, key cost contributors, and technology development.

The first webinar was held in July 2022. Of the 112 people invited, 27 people attended the webinar, and only four provided a completed response form. Due to the limited number of responses received, the study was put on hold, and the future of the study was uncertain. H2O and the National Laboratory of the Rockies decided to continue the study with a new outreach approach. A new targeted list of tidal energy experts was developed, and the list was split into two groups: One group primarily consisted of technology developers, whereas the second group had experts from testing sites, certification bodies, universities, and other technical backgrounds. The expanded list of participants was offered a $1,500 stipend to incentivize participation in the study. To receive the stipend, participants had to attend a webinar (or watch the webinar recording) and submit a completed response form to the project team. The group of technology developers were invited to participate in the study first, with the aim of controlling the number of stipends offered and the group size during the webinar. The second webinar was held in February 2024 for a group of 20 technology developers. After the webinar, the participants were given 6 weeks to submit a completed response form. Of the 20 technology developers invited to participate in the study, five provided completed response forms. Next, the second group of experts were invited to participate in the study and attend a third webinar held in April 2024. Of the 21 experts invited from the second group, four participants provided a completed response form.

2.3 Bias

LCOE estimates may be influenced by optimism bias, which is the tendency for projects or programs to underestimate cost and overestimate benefits in early planning stages. Although there are established methods to account or adjust for optimism bias, the tidal energy industry has insufficient historical data to quantify optimism bias levels; nevertheless, it is acknowledged here for consideration when interpreting results. There are other types of bias (Frazer-Nash Consultancy 2023) that could potentially impact the tidal expert responses, such as:

- A desire to artificially inflate results to obscure data confidentiality and to show greater need for policy and revenue support
- An intent to deflate LCOE to obscure data confidentiality and to sway public opinion by making tidal energy appear less expensive
- Being overly conservative (overcorrecting for optimism bias)
- Basing estimates on incomplete or incorrect knowledge.

However, in this study, we make no attempt to correct for bias because the experts invited to participate are assumed to be reliable sources and were provided an overview of tidal LCOE estimates from the literature to ensure they all had the same background information.

2.4 Analysis

The expert elicitation resulted in 13 completed feedback forms and an additional response that provided only qualitative data. The quantitative and qualitative data were compiled and anonymized for analysis. Due to the limited number of responses, basic statistical analysis was performed on the quantitative data obtained from the feedback forms to find the minimum, maximum, mean, median, and standard deviation of the dataset for each scenario. Using the expert elicitation data, trends were developed for LCOE over time and compared to LCOE estimates from other sources such as publications and funding mechanisms (guaranteed strike prices). The qualitative data obtained from the feedback forms, email, and webinar discussions were compiled into a single anonymized document, which was used to identify common themes in the feedback.

3 Results

The tidal energy LCOE elicitation results are discussed in the following sections. All response data are reported in 2022 USD.

3.1 Quantitative Results From Feedback Forms

This section examines the results yielded from completed feedback forms received from study participants.

3.1.1 LCOE

The 2022 LCOE estimates provided by the study participants have a minimum, maximum, and mean of \$0.20/kWh, \$0.53/kWh, and \$0.36/kWh ± \$0.11/kWh, respectively. On average, the respondents estimated that the LCOE may reach \$0.20/kWh by 2036 ± 6 years for the conservative case and 2033 ± 6 years for the optimistic case. The average LCOE estimates for 2050 under the conservative and optimistic scenarios are \$0.17/kWh ± \$0.08/kWh and \$0.11/kWh ± \$0.06/kWh, respectively. LCOE results by respondent are shown in Table A-1.

Trendlines representing the LCOE over time for each participant for the conservative and optimistic cases and a best-fit line of all responses and scenarios are shown in Figure 4 (conservative) and Figure 5 (optimistic). Two study participants assume LCOE decreases from 2022, then increases in 2050, but they and gave no explanation for this increase.

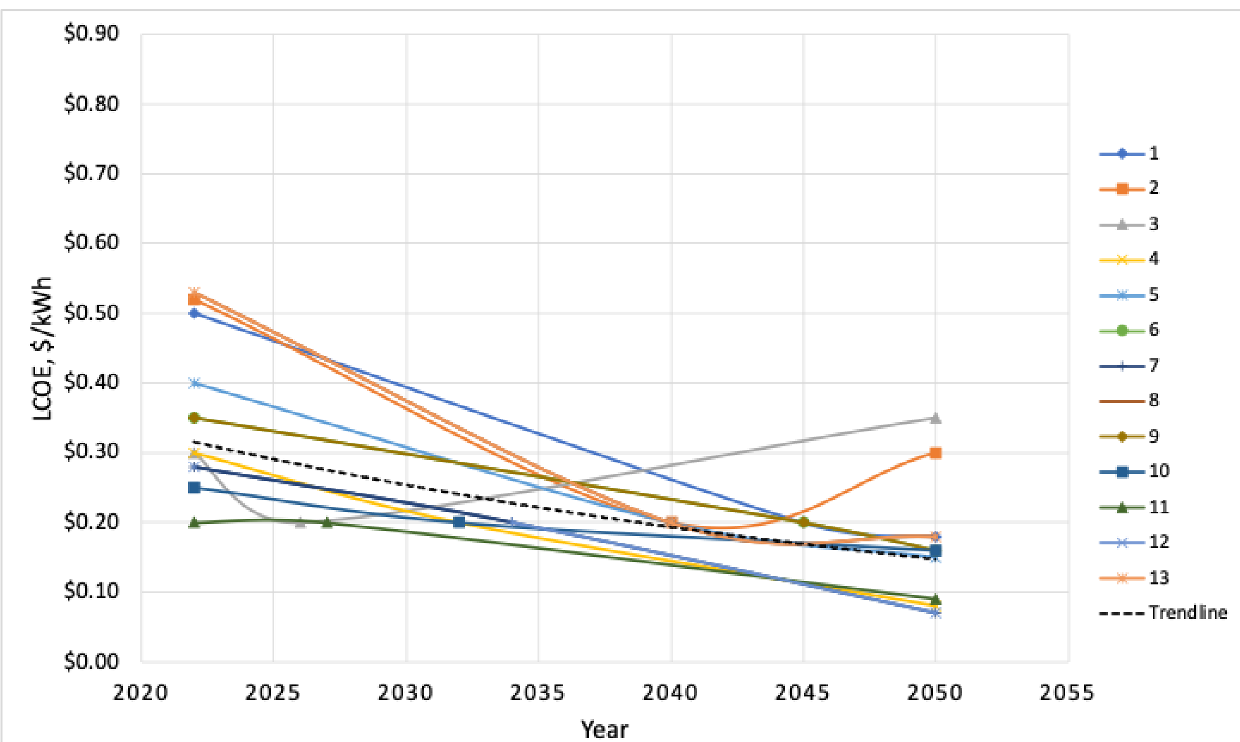


Figure 4. Conservative LCOE estimates over time by respondent

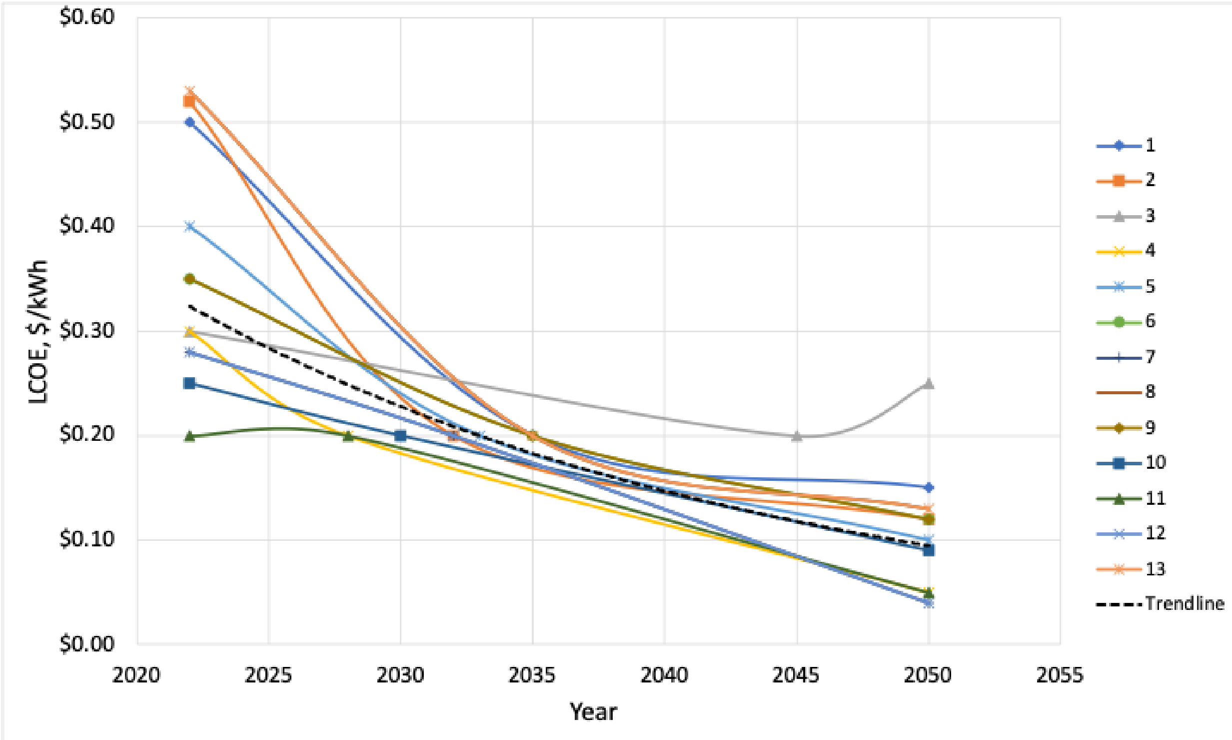


Figure 5. Optimistic LCOE estimates over time by respondent

The average 2050 LCOE estimate decreases for both the conservative and optimistic scenarios in comparison to the 2022 baseline case, as shown in Figure 6, where the mean is represented by an "x" and the whisker shows extreme datapoints. In both scenarios, the 2050 optimistic scenario has the tightest distribution of LCOE estimates with the lowest standard deviation.

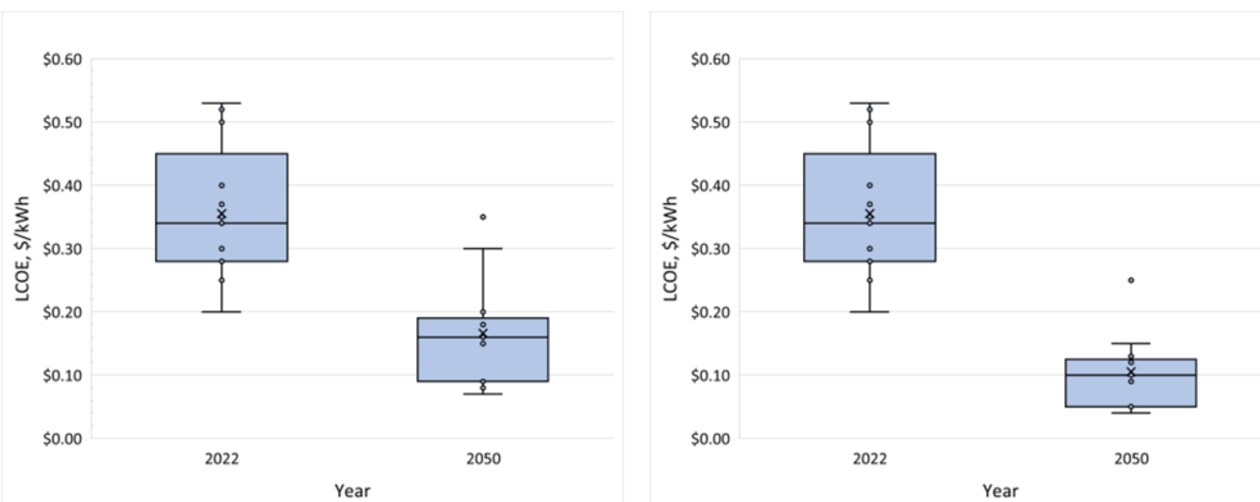


Figure 6. 2022 LCOE versus 2050 LCOE for the conservative (left) and optimistic (right) scenarios

The LCOE estimates shared by the tidal energy experts are generally more conservative than the LCOE estimates presented in the literature, which may indicate that the literature review LCOE data are impacted by optimism bias. Figure 7 shows the tidal energy elicitation LCOE data overlayed on the LCOE data shown in Figure 2. Trendlines created for the conservative and optimistic scenarios highlight how the tidal energy experts tended to be more conservative than the literature review data regarding future years. However, the trendlines show that there is good agreement between the 2022 baseline estimates and the literature review data (indicated by the elicitation trendlines starting on the literature review data trendline) and may suggest that the experts were influenced by the LCOE data in the literature (especially those published in 2022) or that some of the study participants contributed their expert opinion in those studies as well (Frost 2022; Tapoglou et al. 2022; Milne 2020).

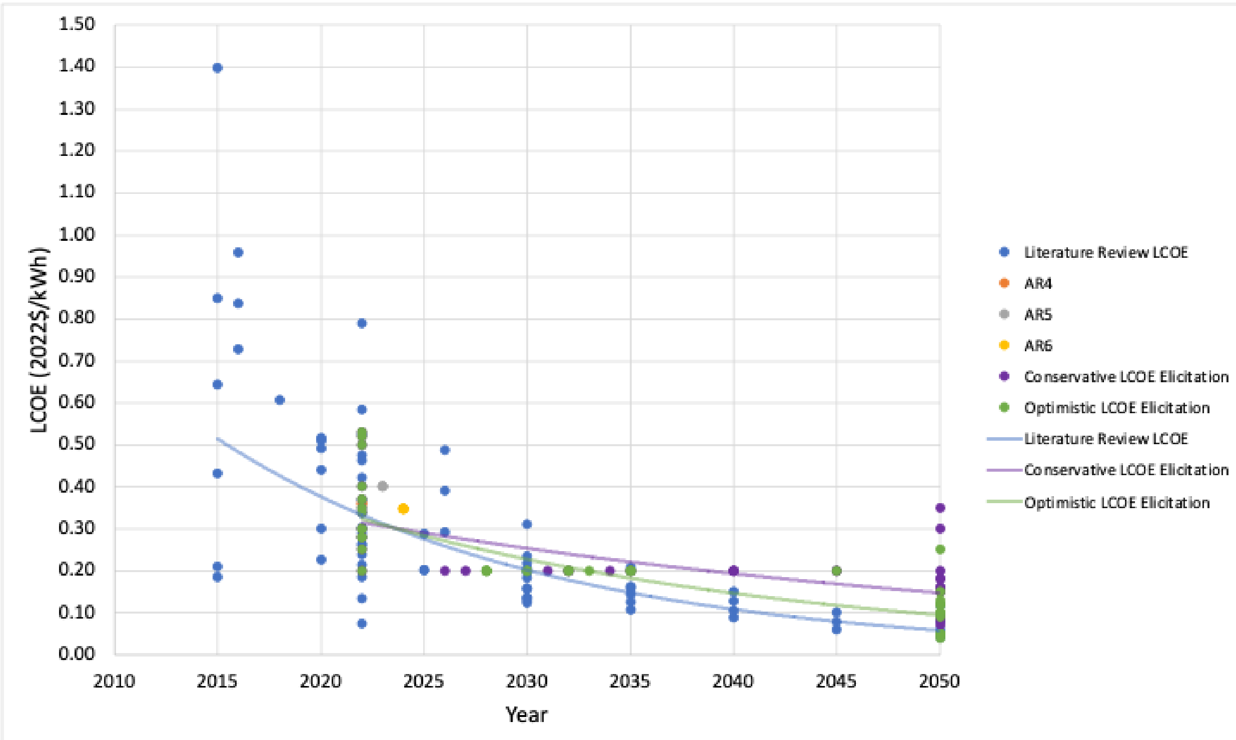


Figure 7. LCOE over time as presented in the literature, CfD information (AR4–AR6), and tidal energy LCOE elicitation

3.1.2 Cost Contributors to LCOE

For each of the five scenarios proposed, each respondent was asked to provide the percentage contribution to LCOE for 12 cost categories. Table 6 and Table 7 compare the 2022 baseline scenario with the $0.20/kWh conservative and optimistic scenarios and with the 2050 conservative and optimistic scenarios, respectively.

Table 6. 2022 Baseline Scenario With the $0.20/kWh Conservative and Optimistic Scenarios

	2022 BASELINE SCENARIO						$0.20/kWh CONSERVATIVE SCENARIO								$0.20/kWh OPTIMISTIC SCENARIO							
Cost Category	MEAN	MEDIAN	STD	MIN	MAX	STD/MEAN	MEAN	MEDIAN	STD	MIN	MAX	STD/MEAN	% CHANGE (MEDIAN)	% CHANGE (MEAN)	MEAN	MEDIAN	STD	MIN	MAX	STD/MEAN	% CHANGE (MEDIAN)	% CHANGE (MEAN)
Structural Assembly	***12.4***	***10.0***	8.1	0.0	27.3	0.66	***12.5***	***10.0***	7.7	0.0	30.0	0.61	0.0%	1.1%	***12.3***	***10.0***	6.7	0.0	25.0	0.54	0.0%	-0.5%
Power Take-Off System	***22.7***	***20.0***	12.5	5.0	50.0	0.55	***24.3***	***24.0***	15.4	8.0	63.0	0.63	**20.0%**	7.2%	***22.6***	***24.5***	12.9	2.0	52.0	0.57	**22.5%**	-0.6%
Mooring, Foundation, & Substructure	***9.8***	***10.0***	5.1	2.4	20.0	0.52	***9.0***	***9.5***	3.4	2.5	15.0	0.38	-5.0%	-8.4%	***8.5***	***9.5***	2.3	3.8	11.0	0.27	-5.0%	**-13.0%**
Development	2.3	2.0	1.5	0.4	5.0	0.67	2.0	1.5	1.4	0.4	5.0	0.71	**-25.0%**	**-12.2%**	3.2	2.0	3.3	0.6	10.0	**1.02**	0.0%	**38.4%**
Engineering & Management	2.6	2.0	1.4	0.9	5.0	0.54	2.6	2.0	1.3	0.9	5.0	0.52	0.0%	0.2%	2.7	2.0	1.2	1.3	5.0	0.45	0.0%	6.3%
Electrical Infrastructure	7.2	7.1	4.2	1.0	15.7	0.58	7.9	6.7	4.6	1.0	16.0	0.57	-5.6%	**10.4%**	8.4	8.5	4.3	1.0	15.0	0.51	**19.7%**	**17.3%**
Plant Commissioning	1.3	1.0	1.2	0.1	5.0	0.91	1.4	1.0	1.5	0.1	6.0	**1.12**	0.0%	2.1%	1.8	1.0	1.6	0.0	5.0	0.85	0.0%	**37.8%**
Site Access, Port, & Staging	1.2	1.0	0.7	0.5	3.0	0.55	1.4	1.0	0.7	0.5	3.0	0.54	0.0%	9.1%	1.3	1.0	0.8	0.5	3.0	0.66	0.0%	1.5%
Assembly and Installation	7.4	7.0	3.6	3.9	15.0	0.49	6.8	7.0	2.9	3.0	11.0	0.42	0.0%	-8.4%	7.8	8.5	2.7	3.6	11.0	0.34	**21.4%**	5.0%
Other Infrastructure	1.1	1.0	0.5	0.1	2.0	0.44	1.1	1.0	0.8	0.0	3.0	0.72	0.0%	0.9%	1.3	1.0	1.2	0.1	5.0	0.91	0.0%	**23.7%**
Financial	4.3	3.0	2.9	1.0	10.4	0.69	3.9	3.0	3.3	1.0	10.9	0.84	0.0%	-7.9%	3.0	1.0	3.5	1.0	10.2	**1.16**	**-66.7%**	**-29.9%**
Operation	***10.8***	***10.0***	4.1	5.0	20.0	0.38	***10.1***	***10.0***	5.1	1.0	20.0	0.50	0.0%	-6.6%	***10.7***	***10.0***	5.0	3.0	20.0	0.47	0.0%	-1.1%
Maintenance	***16.9***	***15.0***	6.6	10.0	30.0	0.39	***17.0***	***17.0***	6.2	10.0	30.0	0.37	**13.3%**	0.6%	***16.3***	***14.4***	7.0	10.0	30.0	0.43	-4.2%	-3.4%
Year							2036	2035	6	2026	2045				2033	2032	6	2028	2045			
LCOE	$0.36	$0.34	$0.11	$0.20	$0.53	0.30								-43.7%								-43.7%
CapEx Contribution	72.3%	74.0%	8.1%	60.0%	84.0%	0.11	72.9%	73.5%	9.3%	60.0%	88.0%	0.13	-0.7%	0.8%	72.4%	75.0%	9.6%	60.0%	86.0%	0.13	1.4%	0.1%
OpEx Contribution	27.7%	26.0%	8.1%	16.0%	40.0%	0.29	27.1%	26.5%	9.3%	12.0%	40.0%	0.34	1.9%	-2.2%	27.6%	25.0%	9.6%	14.0%	40.0%	0.35	-3.8%	-0.3%
Sample Size	N = 13						N = 12								N = 12							

Table 7. 2022 Baseline Scenario With the 2050 Conservative and Optimistic Scenarios

	2022 BASELINE SCENARIO						2050 CONSERVATIVE SCENARIO								2050 OPTIMISTIC SCENARIO							
Cost Category	MEAN	MEDIAN	STD	MIN	MAX	STD/MEAN	MEAN	MEDIAN	STD	MIN	MAX	STD/MEAN	% CHANGE (MEDIAN)	% CHANGE (MEAN)	MEAN	MEDIAN	STD	MIN	MAX	STD/MEAN	% CHANGE (MEDIAN)	% CHANGE (MEAN)
Structural Assembly	***12.4***	***10.0***	8.1	0.0	27.3	0.66	***13.6***	***12.8***	6.9	0.0	25.0	0.51	**27.5%**	**10.30%**	***12.7***	***10.0***	7.3	0.0	25.0	0.57	0.0%	2.74%
Power Take-Off System	***22.7***	***20.0***	12.5	5.0	50.0	0.55	***23.1***	***22.0***	14.6	2.0	58.0	0.63	**10.0%**	1.92%	***24.6***	***24.5***	14.9	2.0	60.0	0.61	**22.5%**	8.42%
Mooring, Foundation, & Substructure	***9.8***	***10.0***	5.1	2.4	20.0	0.52	***10.8***	***10.0***	3.7	5.0	18.0	0.35	0.0%	9.85%	***9.8***	***9.5***	4.4	4.5	20.0	0.45	-5.0%	-0.45%
Development	2.3	2.0	1.5	0.4	5.0	0.67	3.1	3.0	2.3	0.8	10.0	0.75	**50.0%**	**34.56%**	3.0	2.0	2.9	0.3	10.0	**1.00**	0.0%	**27.88%**
Engineering & Management	2.6	2.0	1.4	0.9	5.0	0.54	2.9	2.9	1.3	1.0	5.0	0.45	**42.5%**	**14.62%**	2.6	2.0	1.3	0.8	5.0	0.50	0.0%	-0.20%
Electrical Infrastructure	7.2	7.1	4.2	1.0	15.7	0.58	7.2	7.0	3.3	1.0	12.0	0.46	-1.4%	0.34%	6.6	6.5	3.9	1.0	17.0	0.59	-8.5%	-8.00%
Plant Commissioning	1.3	1.0	1.2	0.1	5.0	0.91	1.6	1.0	1.3	0.1	4.0	0.77	0.0%	**22.03%**	1.6	1.0	1.4	0.1	5.0	0.85	0.0%	**19.23%**
Site Access, Port, & Staging	1.2	1.0	0.7	0.5	3.0	0.55	2.6	2.0	2.4	0.8	9.0	0.89	**100.0%**	**113.51%**	2.4	1.0	2.8	0.3	10.0	**1.14**	0.0%	**95.69%**
Assembly & Installation	7.4	7.0	3.6	3.9	15.0	0.49	6.2	6.0	3.5	1.0	11.0	0.57	**-14.3%**	**-16.50%**	7.1	5.9	3.5	3.7	15.0	0.49	**-16.43%**	-4.42%
Other Infrastructure	1.1	1.0	0.5	0.1	2.0	0.44	1.4	1.0	1.4	0.0	5.0	0.95	0.0%	**31.78%**	1.1	1.0	0.5	0.1	2.0	0.45	0.0%	1.13%
Financial	4.3	3.0	2.9	1.0	10.4	0.69	3.5	1.5	4.1	1.0	13.4	**1.15**	**-50.0%**	**-17.42%**	2.8	1.0	3.6	1.0	13.2	**1.28**	**-66.7%**	**-33.97%**
Operation	***10.8***	***10.0***	4.1	5.0	20.0	0.38	***8.8***	***9.9***	4.4	3.0	20.0	0.50	-1.0%	**-18.45%**	***10.7***	***10.0***	6.4	3.0	25.0	0.60	0.0%	-1.34%
Maintenance	***16.9***	***15.0***	6.6	10.0	30.0	0.39	***14.9***	***13.0***	7.1	8.0	34.0	0.48	**-13.3%**	**-11.54%**	***15.1***	***11.0***	10.9	5.0	45.0	0.72	**-26.7%**	**-10.65%**
Year																						
LCOE	$0.36	$0.34	$0.11	$0.20	$0.53	0.30	$0.17	$0.16	$0.08	$0.07	$0.35	0.50	**-52.94%**	**-53.25%**	$0.11	$0.10	$0.06	$0.04	$0.25	0.55	**-70.59%**	**-69.70%**
Capacity Factor	33.4%	34.0%	6.7%	20.0%	50.0%	0.20	37.6%	38.0%	8.3%	25.0%	55.0%	0.22	**11.76%**	**12.67%**	41.2%	42.0%	9.5%	28.0%	59.0%	0.23	**23.53%**	**23.50%**
CapEx Contribution	72.3%	74.0%	8.1%	60.0%	84.0%	0.11	76.3%	79.5%	8.2%	60.0%	88.0%	0.11	7.43%	5.45%	75.1%	80.0%	11.9%	55.0%	92.0%	0.16	8.11%	3.84%
OpEx Contribution	27.7%	26.0%	8.1%	16.0%	40.0%	0.29	23.8%	20.5%	8.2%	12.0%	40.0%	0.35	**-21.15%**	**-14.24%**	24.9%	20.0%	11.9%	8.0%	45.0%	0.48	**-23.08%**	**-10.02%**
Sample Size	N = 13						N = 12								N = 12							

The top five cost categories are shown in bold italics, and their order remains unchanged in four of the five scenarios ("Operation" and "Mooring, Foundation, and Substructure" are reversed in the 2050 conservative scenario). In order of the highest percentage contribution to LCOE, these categories are:

1. Power take-off system
2. Maintenance
3. Structural assembly
4. Operation
5. Mooring, foundation, and substructure.

A detailed analysis of these top five cost categories reveals the following:

- In all scenarios, the mean percentage for "Power Take-off System" represents more than 22% of the contribution to LCOE and generally increases relative to the 2022 baseline scenario, reaching a maximum mean of 24.6% in the 2050 optimistic scenario.
- When looking at the 2050 conservative and optimistic scenarios, the percentage contribution to LCOE from "Maintenance" decreases in both scenarios.
- The contribution from "Structural Assembly" remains nearly constant in all $0.20/kWh scenarios, with a slight increase in the 2050 scenarios.
- The contribution from "Operation" remains nearly constant in all scenarios, except for an increase in the 2050 conservative scenario.
- The contribution from "Mooring, Foundation, and Substructure" decreases in the $0.20/kWh scenarios, increases in the 2050 conservative scenario, and remains nearly constant in the 2050 optimistic scenario.

To further understand the results, the largest changes in both mean and median values relative to the 2022 baseline scenario are shown in bold, along with any dataset that has a standard deviation greater than the mean.

A detailed analysis of these changes to the mean values in each cost category reveals the following:

- When looking at the 2050 conservative and optimistic scenarios as defined in Section 3.1, the largest increased change in LCOE contribution is in the "Site Access, Port, and Staging" category, with increases relative to the 2022 baseline scenario of 113.51% and 95.69%, respectively.
- When looking at the 2050 conservative and optimistic scenarios, the largest decreased change in LCOE contribution is in the "Financial" category, with decreases relative to the 2022 baseline scenario of −17.42% and −33.97%, respectively. It should be noted that the 2050 conservative scenario shows a −18.45% change in the "Operation" category; however, this category is nearly unchanged in the 2050 optimistic scenario.
- When looking at the $0.20/kWh conservative scenario, the changes in LCOE contributions compared to the 2022 baseline scenario are relatively small.
- When looking at the $0.20/kWh optimistic scenario, the changes in LCOE contributions compared to the 2022 baseline scenario are larger, with the largest increases in the

"Development" and "Plant Commissioning" categories and the largest decrease in the "Financial" category.

When examining the distributions with a standard deviation larger than the mean, the following observations are noted:

- For the $0.20/kWh conservative scenario, specifically the "Plant Commissioning" category, a single data point is responsible for the large standard deviation. This is confirmed by the unchanged median value relative to the 2022 baseline scenario.
- For the $0.20/kWh optimistic scenario, four respondents had dramatically different perspectives for the "Development" and "Financial" categories. Specifically, two respondents gave each category a very high contribution, whereas the other two gave the same category a very low contribution, and vice versa. In both categories, these disparate perspectives led to elevated standard deviations and significant changes to the mean.
- For the 2050 conservative scenario, the "Financial" category had two responses that led to the increased standard deviation. Without these two data points, the associated reduction in the percentage change of the median and mean relative to the 2022 baseline would have been even greater.
- For the 2050 optimistic scenario, a trend in the data similar to the $0.20/kWh optimistic scenario was observed: Two respondents had dramatically different perspectives for the "Site Access, Port, and Staging" and "Financial" categories. Specifically, one respondent gave each category a very high contribution, whereas the other gave the same category a very low contribution, and vice versa.

For all scenarios, the percentage contribution from "Structural Assembly" and "Engineering and Management" to LCOE remain nearly constant. Among the balance-of-system cost categories, "Electrical Infrastructure" and "Assembly and Installation" are the leading cost contributors to LCOE. The "Electrical Infrastructure" percentage contribution initially increases compared to the baseline, then decreases in future years, with the greatest decrease in the optimistic 2050 scenario. The LCOE percentage contribution from the "Assembly and Installation" cost category decreases over time compared to the baseline for the conservative scenario. In the optimistic scenario, the "Assembly and Installation" percentage contribution initially increases compared to the baseline, then decreases in 2050. Interestingly, the "Assembly and Installation" percentage contribution to LCOE shows a greater decrease for the conservative case than for the optimistic case, for which there is no clear explanation.

3.1.3 Capacity Factor

Respondents provided the assumed CF for the hypothetical tidal energy array that informed the LCOE estimates for each scenario. For the 2022 baseline scenario, the minimum, maximum, mean, and median assumed CFs are 20%, 50%, 33%, and 34%, respectively. Figure 8 and Figure 9 show the CF over time for each respondent. Table A-2 shows CF estimates for each respondent and scenario. For the conservative scenario, the mean assumed CF initially remains constant and then increases in 2050. For the optimistic scenario, the mean assumed CF gradually increases over time. The mean CF of 42% in the optimistic 2050 case has the greatest increase overall. It should be noted that CF responses for Respondent 11 (dark green line) seemed unusual, and we thought that some of the CF values may be errors; however, when we reached out to confirm the accuracy of the CF data for Respondent 11, we did not receive a response. We decided to include all respondent data for the CF statistical analysis, which would change if the CF data from Respondent 11 includes unintended response data.

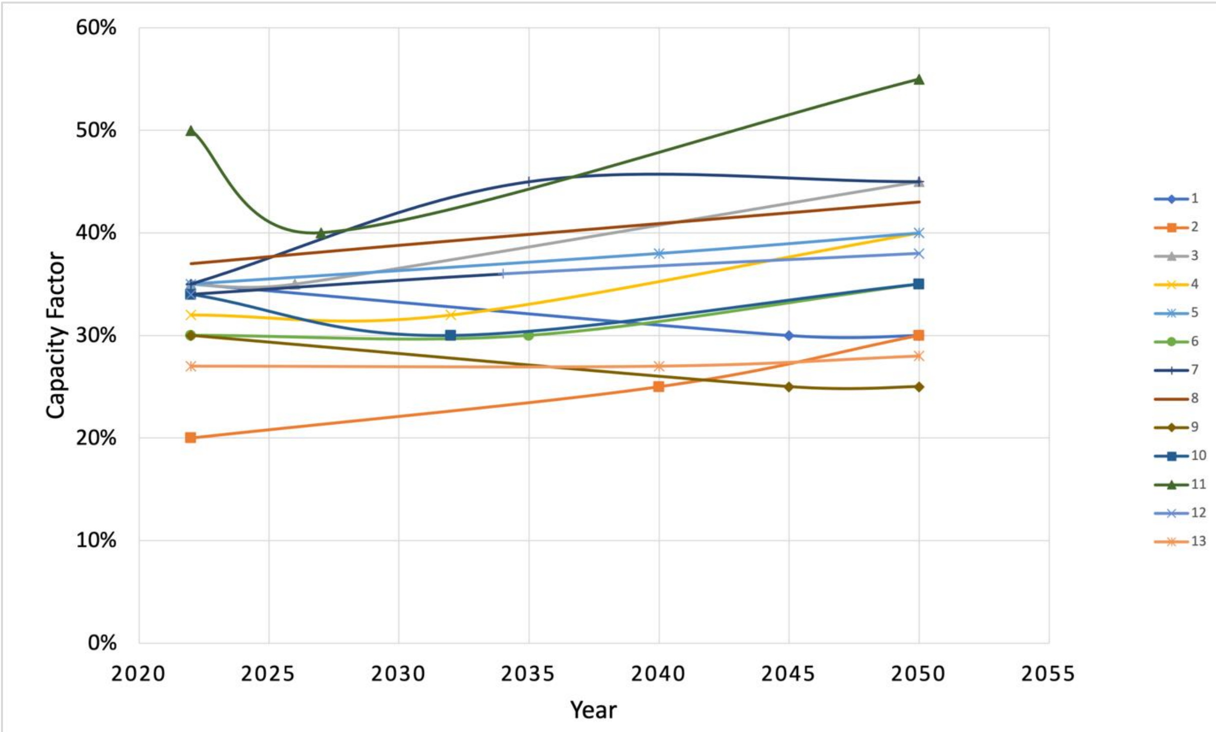


Figure 8. CF over time by respondent for the conservative scenario

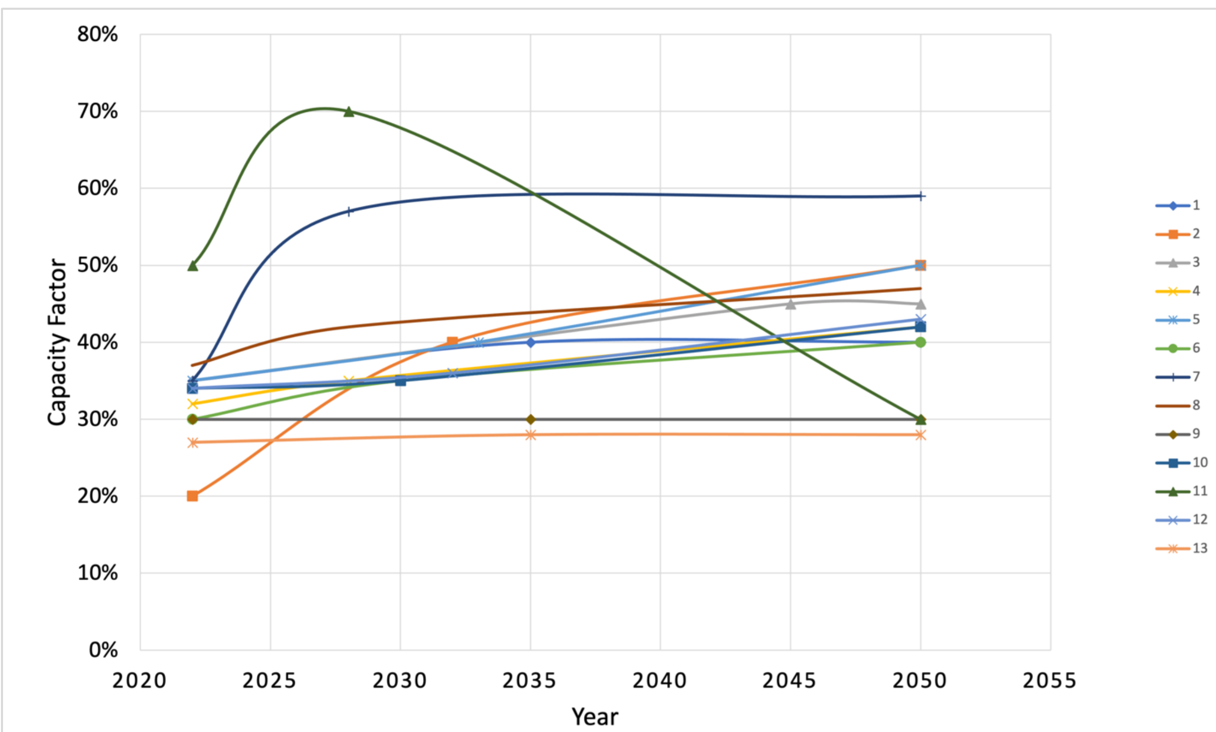


Figure 9. CF over time by respondent for the optimistic scenario

3.1.4 Rated Power

Respondents provided the assumed rated power of the tidal energy device used in the hypothetical array that informed the LCOE estimates for each scenario. For the 2022 baseline scenario, the minimum, maximum, and mean assumed rated power are 0.02 MW, 4 MW, and 1.55 MW ± 0.98 MW, respectively. In all scenarios, one respondent assumed a rated power of 200 kW, which is 2 orders of magnitude less than the next highest estimate. In the 2050 conservative scenario, the mean assumed rated power increases to 2.18 MW, and in the 2050 optimistic scenario, the mean assumed rated power increases to 3.64 MW. In some cases, respondents specified that the device has dual rotors, whereas others provided a more generic technology type such as a horizontal-axis turbine. Therefore, all rated power estimates shown in Table A-3 are assumed to be for a single device and not per rotor. Figure 10 and Figure 11 show rated power over time for the conservative and optimistic scenarios, respectively.

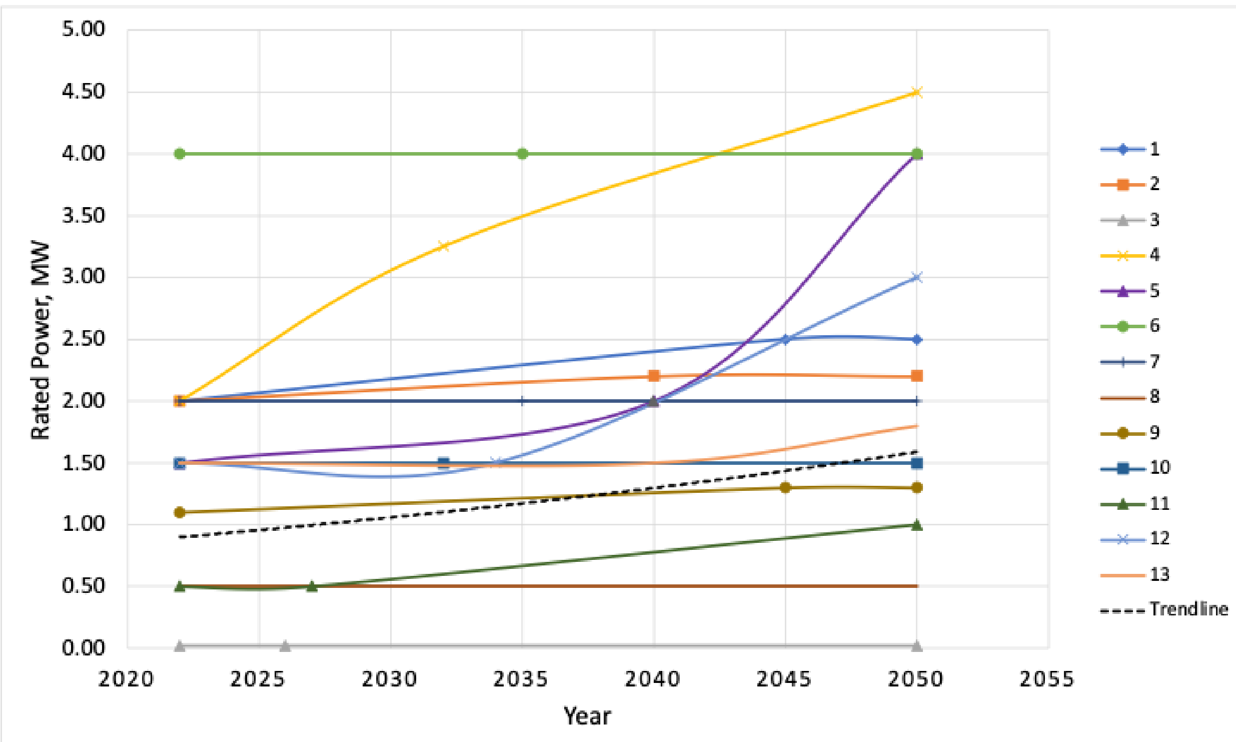


Figure 10. Assumed rated power per device versus time for the conservative scenario

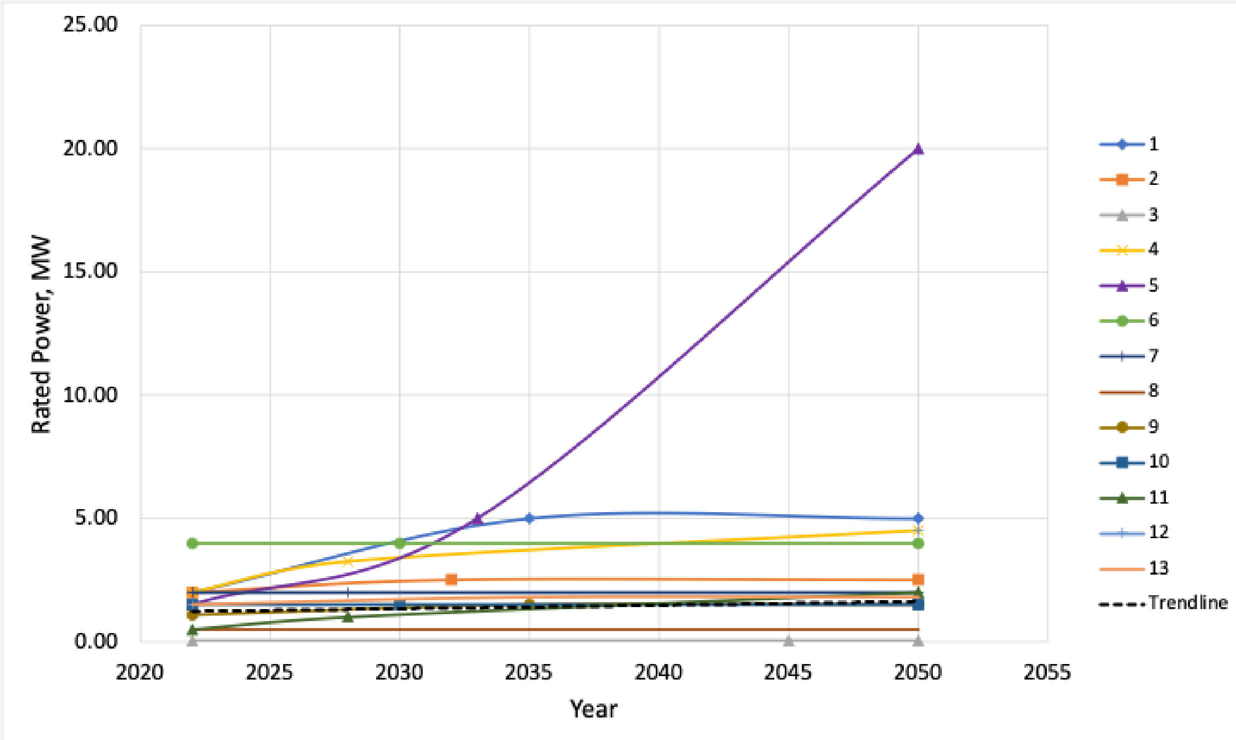


Figure 11. Assumed rated power per device versus time for the optimistic scenario

3.1.5 Cumulative Global Installed Capacity

In all scenarios, the assumed cumulative global capacity varied greatly across participants, with the maximum assumed value being at least 2 orders of magnitude more than the minimum assumed value in each scenario. However, there was general agreement that the cumulative global installed capacity will increase over time, except one participant assumed a constant value for all scenarios. The increase in global installed capacity correlates with a decrease in estimated LCOE over time. While some of the capacity estimates might seem unrealistic in 2022, these are the assumed capacity estimates for the corresponding LCOE estimates. Remember that these estimates represent a hypothetical 100-MW array, which also did not exist in 2022. All LCOE estimates may include economies of scale and technological learning which is driven by capacity.

The cumulative global installed capacity over time for the conservative and optimistic scenarios is shown in Figure 12 and Figure 13. Both plots show the global cumulative installed capacity on a logarithmic scale, and although there is little agreement among the participants in each scenario, the plot shows a clear upward trend from 2022 to 2050. The cumulative global installed capacity assumed by each participant for each scenario is shown in Table A-4.

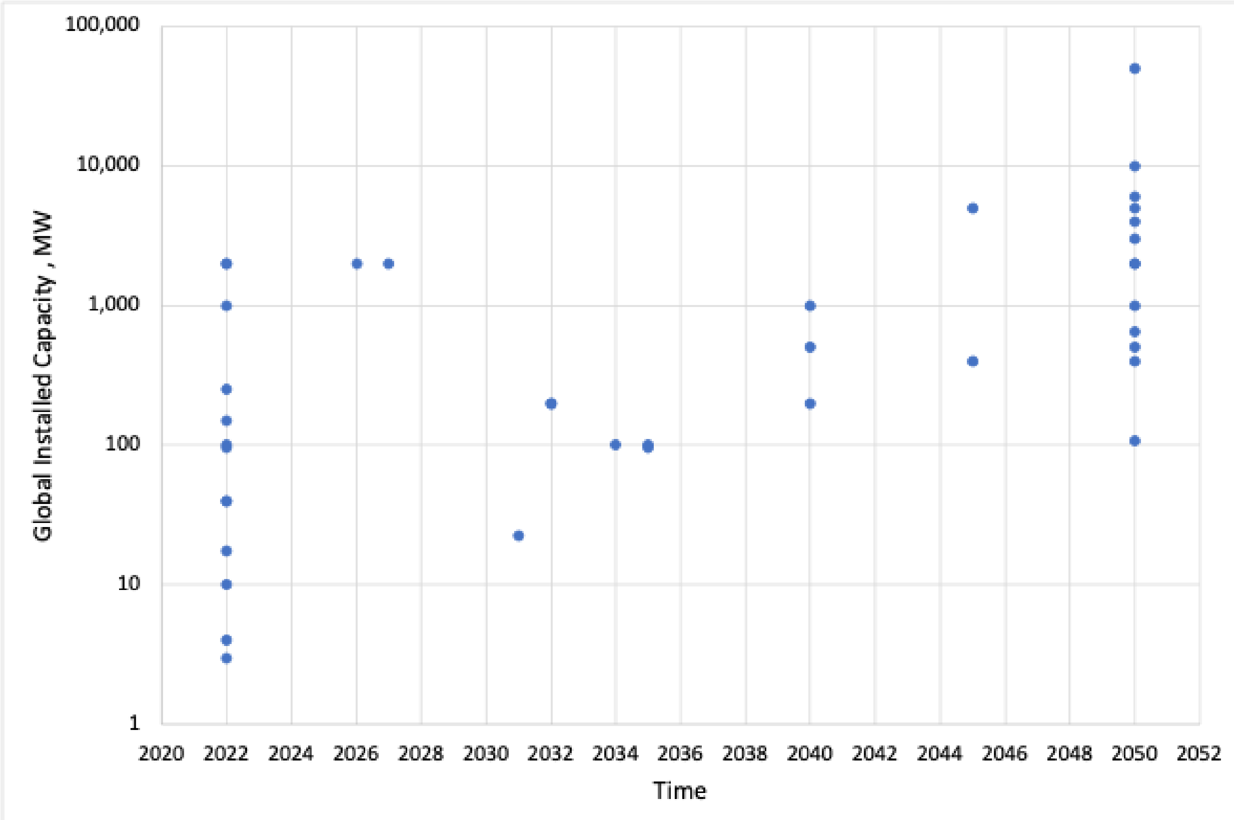


Figure 12. Cumulative global installed capacity over time for the conservative scenario

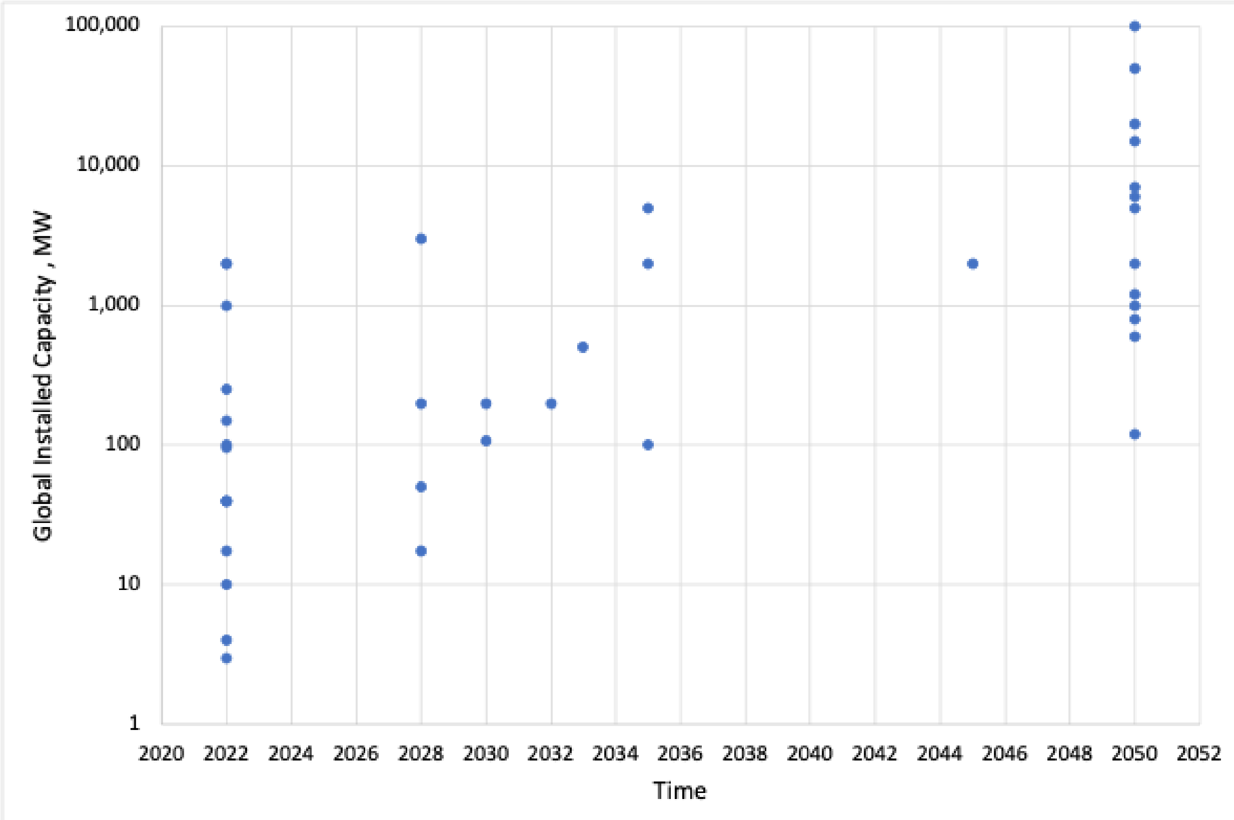


Figure 13. Cumulative global installed capacity over time for the optimistic scenario

3.1.6 Water Depth

Respondents assumed a water depth for the hypothetical array, which they used to inform their LCOE estimates. The assumed water depth for each scenario and respondent is shown in Table A-5. Some participants assumed a constant water depth for all scenarios, whereas others assumed an increase in water depth over time. However, one respondent (Respondent 9) assumed that the water depth decreased in the 2050 scenario compared to the baseline case. For all scenarios, the minimum and maximum values are 10 meters (m) and 150 m, respectively. The mean assumed water depth is 49 m in the 2022 baseline case and increases to 52 m in the conservative and optimistic 2050 scenarios.

3.1.7 Distance to Shore

Respondents assumed a distance to shore for the hypothetical array, which they used to inform their LCOE estimates, as shown in Table A-6. Some respondents assumed a constant distance to shore for all scenarios, whereas others assumed that the distance to shore increased over time. The minimum and maximum values are the same for all scenarios—1 kilometer (km) and 20 km, respectively. The average distance to shore for the baseline case is 7 km and increases to 8 km for the 2050 conservative and optimistic scenarios.

3.2 Qualitative Results From Feedback Forms

As a part of the tidal elicitation, respondents were given the opportunity to provide general feedback. In some cases, the feedback is focused more on the data collection methods of the study itself. The following summarizes the input received from the elicitation respondents:

- Developers have capitalized on the available revenue support mechanisms of the CfD in the United Kingdom and the feed-in tariff in Canada.
- Developers expressed concerns that further projects will not benefit from such generous revenue support and thus the future market potential is entirely dependent on significantly reduced LCOE of tidal projects, ultimately reaching parity with other forms of renewable energy.
- A staged approach to cost reduction is required, similar to that of the offshore wind industry, which realized cost reductions over decades with financial and revenue support, ultimately achieving parity with wholesale electricity prices.
- Key technical areas for cost reductions include:
    - Technology development
    - Turbines
    - Electrical balance of plant and cables
    - Foundation
    - Marine services.
- Key pathways for cost reductions include:
    - Economies of scale
    - Lower cost of capital.
- The single biggest barrier to progress is in relation to the apportion of risk associated with innovation. In simple terms, developers cannot provide an extensive warranty on any new technology with limited (or no) operating hours. Similarly, project developers and funders do not want to purchase turbines and other equipment without extensive warranties. The first step is therefore to demonstrate technology-related cost reductions by means of small demonstration projects, e.g., 1–3 units. After a trial operation period, it would be possible to deliver more of these machines with commercial warranties to demonstrate cost reduction associated with economies of scale by delivering projects with 10 or more units.

In addition to the general feedback provided above, specific feedback on each scenario was provided and is summarized here:

- The mooring and anchoring systems are expensive and could contribute up to 30% of the total cost. During the design stage, we need to consider the strength adequacy and fatigue life of the mooring line with safety factors. Also, there is a high safety factor for anchor holding capacity. Anchors should be proof tested after installation.
- The CF of tidal energy projects can vary depending on factors such as tidal resources, project location, technology efficiency, and operational considerations. CFs typically range from 20% to 40%, but they can vary substantially based on project location.

- It is hard to separate electrical infrastructure (equipment) costs from installation costs, particularly for onshore substations (because of the nature of typical contracts).
- The economy-of-volume scaling for CapEx estimates and CapEx breakdowns assumed are rough approximations, and there is room for improvement. It would be interesting to get other perspectives on the appropriate weighted average cost of capital, or discount rate. Similarly, it would be interesting to get other perspectives on what proportion to assume for insurance, contingency, project management, etc.
- As technology advances in the tidal energy sector, it is likely that the percentage contribution from CapEx to LCOE will decrease. This reduction can be attributed to various factors such as improved turbine designs, increased efficiency in installation processes, streamlined manufacturing, and economies of scale as more projects are deployed. Over time, it is reasonable to expect that with continued research, development, and deployment, the cost of tidal power take-off systems could decrease over time. Innovations in materials, design, and manufacturing processes could contribute to cost reduction. In addition, with more experience in installation and assembly, this cost may also decrease. Eventually, more cost will come from operation, maintenance, monitoring, and inspection.
- For the CapEx split between the converter and the balance of system, it is optimistically assumed that a 50/50 split in costs can shift more toward a 75/25 split, where the tidal energy converter becomes the primary component of cost. It is further assumed that by 2050 the industry will be able to make larger blades while maintaining similar power ratings, which will lower the rated velocity of the devices, thus improving the CF.
- Development of the following is required to achieve cost reductions assumed in the study responses for large arrays, in addition to general learning through experience and gradual technological improvements:
    - More cost-effective electrical architecture for large arrays
    - More cost-effective mooring and anchoring systems for floating platforms
    - More robust dynamic cables for floating platforms
    - Significant reductions in insurance premiums for offshore projects
    - A streamlined consents system to enable large utility-scale projects (often in more sensitive areas) to be consented faster
    - Ongoing revenue support in the early years of deployments.

4 Discussion

The analysis of the data obtained from respondents via the feedback form showed some clear trends and was helpful in identifying leading cost contributors to LCOE. However, in some cases, the results were confusing and had little agreement, which stress the study's limitations, as discussed in Section 5.2.

4.1 Trends

In this study, many clear trends are identified regarding LCOE, CapEx, OpEx, CF, and project cost allocation.

LCOE reduction over time. As discussed in Section 4, respondents expected the LCOE to decrease over time; however, the experts did not always agree on LCOE estimates or on how reductions will be achieved. Interestingly, there was more agreement for LCOE estimates in future years than the present baseline case, so although the experts did not share consensus for the baseline case, they were more confident of where LCOE needs to be in the future for tidal energy to be considered an affordable renewable generation technology. The feedback form itself did not capture all aspects of expected LCOE reduction; however, respondents generally assumed an increase in CFs and global cumulative installed capacity. Additionally, some respondents assumed an increase in device rated power, whereas others assumed the industry would develop the ability to make larger blades while maintaining similar power ratings to lower the rated velocity of the device but improve its CF.

Decrease in OpEx contribution to LCOE over time. Respondents expected the OpEx contribution to LCOE to decrease, which is driven by reductions in the contribution from maintenance that are most pronounced in the optimistic scenarios. Reductions in maintenance costs are achievable through improved technology reliability, improved technology maintainability, increased maintenance cycle intervals (some developers are targeting maintenance cycles of up to 5 years), and gaining experience (learning by doing) with initial deployments.

CapEx cost allocation shift over time. The percentage contribution from CapEx to LCOE increases slightly over time (to compensate for the reduction in OpEx) but shifts in terms of how costs are allocated. Assessing and comparing the LCOE percentage contribution from CapEx cost categories was arguably the more challenging aspect of the analysis, and due to the limited number of responses, the significance of the results in some cases is questionable. Therefore, we focused on the cost categories that were assumed to be the largest contributors to LCOE and those that showed the largest change in LCOE contribution over time. The LCOE contribution from the "Financial" cost category in terms of CapEx decreased in the future estimations, implying that respondents expect the cost of financing and insurance (during construction and installation) to be driven down, likely due to de-risking technology and proving reliability in early deployments. Meanwhile, the "Site Access, Port, and Staging" and "Development" cost categories increased in the mean percentage LCOE contribution in future years. This result could be attributable to the fixed costs associated with these cost categories taking a larger portion of the CapEx LCOE contribution as other cost categories are reduced from future innovation and optimization.

The top cost drivers to tidal energy LCOE were identified. Three of the top five identified cost contributors to LCOE are device-related costs. Ranked in order from highest to lowest, "Power Take-Off System," "Structural Assembly," and "Mooring, Foundation, and Substructure" were all identified as key contributors to LCOE. As the top contributor to LCOE, reducing cost related to "Power Take-Off System" requires innovations in design, materials, and manufacturing processes. Reductions in the "Structural Assembly" cost may also depend on innovation and optimization of the structure itself, manufacturing processes, and on supply chain development. Although all components would benefit from a more developed supply chain, the structure is particularly sensitive, as it is neither feasible nor economical to transport structures weighing hundreds of metric tons across long distances. Therefore, there is a need for manufacturers close to coastlines or for the device to be composed of several smaller packages to limit the package size and weight with lower lifting requirements and reduced logistical transportation constraints. Experts expressed a need for cost reductions in "Mooring, Foundation, and Substructure" components and hope for innovations that allow for easier installation and maintenance. Among the balance-of-system costs, "Assembly and Installation" and "Electrical Infrastructure" are assumed to be the largest contributors to LCOE, and their percentage contributions to LCOE are expected to decrease over time. Similar to OpEx, "Assembly and Installation" costs are assumed to decrease through learning by doing and economies of scale achieved in future deployments.

Deployments leading to increased installed capacity drive down costs over time. The participants agreed that LCOE reductions would be heavily influenced by economies of scale, economies of volume, learning by doing, and innovations through R&D. They also expressed the need for financial and revenue support in early-stage, single-device deployments and demonstration arrays. The experts emphasized the importance of the complementary and self-reinforcing cycle between deployments and cost reduction, as each deployment helps to lower costs and drive more deployments in the future. They also stressed how financial and revenue support is necessary to initiate the symbiotic relationship between deployments and cost reduction. The experts are also counting on cost reductions in insurance and cost of capital that will only come to fruition when technologies have been de-risked and proven to be reliable in long-term deployments. Their feedback highlights the need for financial support to make early deployments attainable and the importance of mitigating risks to avoid preventable failures during initial deployments, as failures can impact the bankability and insurance rates for the industry for many years to come.

4.2 Study Limitations

The first and greatest limitation of the study was the number of participants. The study fell short of achieving the goal of securing at least 15 participants. Since the tidal energy industry is smaller than other renewable energy industries, the study's lack of participants may be partially attributed to the small pool of tidal energy experts to draw from. However, regardless of the reason, having a small sample size made it challenging to do meaningful statistical analysis of the data obtained. There was little agreement on the baseline case, and perhaps with more participants, outliers could have been identified to reach a consensus. Second, there were limitations related to the data collection methods. Ideally, the research team would have set the baseline case rather than have participants define their own baseline, but due to the lack of publicly available data, the latter method was used. Third, the feedback form had limitations and was cumbersome for users to complete. In retrospect, there are many aspects of the feedback form that we would change in future studies. Particularly, multiple respondents raised an issue with the use of the CF as a lever to change the annual energy production. Alternatively, to gain insight into the expected annual energy production, the technology being assumed, and how it may change over time, additional questions focused on the technology could be included, such as questions related to the assumed tidal rotor diameter and the number of turbines per device. Fourth, some participants expressed that 2050 was too far in the future, making it challenging to conceptualize, and that it would be preferable to have the scenarios follow a sequence of years closer to the present year. Lastly, the application of expert elicitation for new technologies with limited technology convergence and real-world deployment experience may lead to diverse thinking on the best technological development path to reach commercialization and may be a factor in the high diversity in the study's results.

4.3 Industry Positions

As discussed in Section 2.1, industry trade associations are actively working to support and grow the tidal energy industry. In addition to providing installed capacity targets, these organizations are working to identify industry priorities and provide key recommendations, as summarized below.

1. The NHA-MEC's *Position Paper 3: Marine Energy Priorities* report (NHA-MEC 2024) presents the following key recommendations:
    A. Substantially increase federal funding for private sector technology developers.
    B. Increase the number of funding opportunities and issue them on a more regular schedule.
    C. Establish a continuum of funding among multiple DOE offices.
    D. Eliminate cost share requirements in funding opportunities.
    E. Implement stage-gated funding from small systems up to large system development.
    F. Increase component and subsystem research, development, and demonstration funding.
    G. Improve and simplify regulatory processes.
2. The U.K. Marine Energy Council recommended five actions to the new U.K. government (NHA-MEC 2021):
    A. Increase the tidal stream ringfence to £30 million in the AR6 renewable auction.
    B. Set a 1-GW tidal stream target for 2035.
    C. Set a 300-MW wave energy target for 2035.
    D. Streamline and prioritize the consenting of marine energy projects.
    E. Introduce innovation support for marine energy.
3. Marine Energy Wales' *State of the Sector 2024* report (Marine Energy Wales 2024) presents the following key items to enable the scale-up of tidal energy:

A. Visibility and surety of future project pipelines

B. A guaranteed and continued route to market through the annual CfD auction round

C. Bespoke financial products

D. Collaboration on supply chain development

E. Removal and reduction of environmental risks using all relevant U.K.-wide evidence.

In addition to the documents referenced above, several relevant reports offer recommendations to accelerate the commercialization of the tidal energy industry:

- Offshore Renewable Energy Catapult's 2024 *Tidal Stream Technology Roadmap* (ORE Catapult 2024)
- Supergen's 2023 *Ocean Energy and Net Zero: Policy Support for the Cost Effective Delivery of 12GW Wave and Tidal Stream by 2050* (Wong, Grattan, and Jeffrey 2023).

4.4 LCOE Reduction Support Mechanisms

To promote tidal energy adoption and accelerated tidal energy LCOE reduction in the United States there is need for:

- Setting installed capacity and LCOE targets for tidal energy with clear strategies for achieving those targets
- Developing robust protected (ringfenced) revenue support mechanisms to support tidal energy projects for the duration of their project life (15–20 years) with the aim of advancing tidal energy technologies over the next decade
- Developing other financial support mechanisms that promote private investment in industry.

Based on the summary of data collected and existing literature, we propose the following support mechanisms for consideration:

1. The United States could develop capacity targets for tidal energy in the future (2035, 2050, etc.) and clear strategies for achieving those targets. The targets outlined by NHA-MEC and other global targets could be used as a starting point.

2. The United States could develop targets for LCOE in the future (2035, 2050, etc.) and implement clear strategies for achieving those targets.

3. The United States could develop and implement a favorable 15- to 20-year tidal energy revenue support mechanism (based on energy productions like feed-in tariffs or CfDs) to advance tidal energy in the 2025–2035 timeframe. The following aspects could be considered:

    A. A robust protected (ringfenced) budget for tidal energy.

    B. The revenue mechanism should avoid additive funding constraints to ensure that recipients of the revenue support are not prevented from pursuing additional non-dilutive grant funding.

4. DOE could consider extending initiatives for tidal energy until 2035 and provide low-cost project support to achieve at least 1 GW of installed capacity in the 2030–2035 timeframe. Support needs to be high enough for a 10% unlevered return to attract project finance debt. Support could also take the form of streamlining the H2O grant process to a more performance-based award system for projects at high technology readiness levels or eliminating go/no-go review delays to allow for realistic project implementation compared with the current mechanism. At technology readiness levels 7/8/9, projects are no longer research and development projects, and although they could benefit from lab and university involvement and support, they would benefit from fewer administrative hurdles to achieve LCOE targets. To achieve this pace, the opportunities should be directed by the marine sector as much as possible.
5. Other financial and revenue support mechanisms could be considered, payable by the federal or state governments or municipalities, to provide additional revenue for tidal energy projects. Such additional non-dilutive revenue is critical to attract private investment and to ensure that a return on investment can be realized in the initial execution of commercial tidal energy projects.

5 Conclusion

The tidal energy LCOE elicitation was successful in obtaining quantitative and qualitative data related to tidal energy LCOE. This study estimates a mean LCOE in 2022 of \$0.36/kWh ± \$0.11/kWh for tidal energy. On average, the respondents estimated that tidal energy LCOE may reach \$0.20/kWh by 2036 ± 6 years for the conservative case and 2033 ± 6 years for the optimistic case. The average estimate for tidal energy LCOE in 2050 under the conservative and optimistic scenarios is \$0.17/kWh ± \$0.08/kWh and \$0.11/kWh ± \$0.06/kWh, respectively. The experts identified the leading cost contributors to tidal energy LCOE, which include:

1. Power take-off system
2. Maintenance
3. Structural assembly
4. Operation
5. Mooring, foundation, and substructure
6. Electrical infrastructure
7. Installation.

Other key takeaways from the study include the following:

- There is no single action to reduce tidal energy LCOE. Instead, future LCOE reduction will rely on the combination of economies of scale, economies of volume, learning by doing, and technological innovation through R&D.
- The experts emphasized the mutually beneficial relationship between deployments and cost reduction, where more deployments lead to more cost reduction, and accentuated the importance of financial and revenue support to kick-off deployments that lead to further cost reductions and drive future deployments.
- There is a need for a streamlined consenting process that enables tidal energy projects to be consented faster.
- Risk is a significant barrier to early tidal energy projects that contributes to high insurance cost and high cost of capital. Risk also makes investors and project developers reluctant to support tidal energy deployments.
- Ongoing financial and revenue support throughout early deployments of single-unit and multi-unit array demonstrations is essential to harness LCOE reductions driven by cumulative installed capacity. This support will help tidal energy technologies overcome initial deployment barriers associated with high costs and risks and will support projects to gain operational hours that prove technical performance and reliability while derisking technologies and offshore operations.

These study results may be used to complement and recalibrate assumptions in bottom-up LCOE analysis, inform future research priorities, and inform strategies to advance tidal energy technologies.

References

Baca, Elena, Ritu Treisa Philip, David Greene, and Hoyt Battey. 2022. *Expert Elicitation for Wave Energy LCOE Futures*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5700-82375. https://www.nlr.gov/docs/fy22osti/82375.pdf.

California State Senate. 2023. *An act to add Chapter 18 (commencing with Section 25996) to Division 15 of, and to repeal Section 25996.1 of, the Public Resources Code, relating to energy*. SB-605. Approved by Governor October 7, 2023. Filed with Secretary of State October 07, 2023. https://legiscan.com/CA/text/SB605/id/2832256.

Carlsson, Johan, Roberto Lacal Arantegui, Arnulf Jager-Waldau, Andrei Bocin-Dumitriu, Bergur Sigfusson, Ghassan Zubi, Davide Magagna, et al. 2014. *2013 Technology Map of the European Strategic Energy Technology Plan*. Luxembourg: European Commission Joint Research Centre. http://dx.doi.org/10.2790/99812.

Collombet, Rémi, and Donagh Cagney. 2022. *Last Stop to 2025: A 2022 Action Plan To Deliver on the Offshore Strategy's Ocean Energy Target*. Brussels, Belgium: Ocean Energy Europe. https://www.oceanenergy-europe.eu/wp-content/uploads/2022/06/Last-Stop-to-2025.pdf.

Congress.gov. 2007. "Text - H.R.6 - 110th Congress (2007–2008): Energy Independence and Security Act of 2007." Dec. 19, 2007. https://www.congress.gov/bill/110th-congress/house-bill/6/text.

Department for Energy Security and Net Zero. 2016. "Contracts for Difference." GOV.UK. Accessed July 17, 2024. https://www.gov.uk/government/collections/contracts-for-difference.

Directorate-General for Maritime Affairs and Fisheries. 2024. "WaveFarm Unleashes a Wave of Energy for a Sustainable Future." European Commission. January 31, 2024. https://oceans-and-fisheries.ec.europa.eu/news/wavefarm-unleashes-wave-energy-sustainable-future-2024-01-31_en.

European Commission. 2016. "SET Plan – Declaration of Intent on Strategic Targets in the Context of an Initiative for Global Leadership in Ocean Energy." Accessed Nov. 2, 2021. https://setis.ec.europa.eu/system/files/2021-04/declaration_of_intent_ocean_0.pdf.

Frazer-Nash Consultancy Limited. 2023. *Review of Technical Assumptions and Generation Costs: Levelised Cost of Electricity from Tidal Stream Energy*. London, England: U.K. Department for Energy Security and Net Zero. https://assets.publishing.service.gov.uk/media/655372484ac0e1001277d819/tidal-lcoe-report.pdf.

Frost, Ciaran. 2022. *Cost Reduction Pathway of Tidal Stream Energy in the U.K. and France*. Hayle, England: Tidal Stream Industry Energiser. https://cms.ore.catapult.org.uk/wp-content/uploads/2022/10/Tidal-stream-cost-reduction-report-T3.4.1-v1.0-for-ICOE.pdf.

Gardner, Michael, Gregor MacAskill, Shelley MacDougall, Richard Karsten, Stephanie Maillet, James Taylor, Sandy Kerr, Kate Johnson, and Joe Fitzharris. 2015. *Value Proposition for Tidal Energy Development in Nova Scotia, Atlantic Canada and Canada.* Halifax, Nova Scotia: Offshore Energy Research Association. https://tethys.pnnl.gov/sites/default/files/publications/Gardner-et-al-2015.pdf.

Huckerby, J., H. Jeffrey, A. de Andres, and L. Finlay. 2016. *An International Vision for Ocean Energy 2017*. Lisbon, Portugal: Technology Collaboration Programme on Ocean Energy Systems. https://www.ocean-energy-systems.org/publications/oes-vision-strategy/document/oes-vision-for-international-deployment-of-ocean-energy-2017-/

International Electrotechnical Commission (IEC). 2022. "Area: 417: Marine Energy - Wave, Tidal and Other Water Current Converters." Accessed July 17, 2024. https://www.electropedia.org/iev/iev.nsf/index?openform&part=417.

International Renewable Energy Agency (IRENA). 2020. *Innovation Outlook: Ocean Energy Technologies*. Abu Dhabi: IRENA. https://www.irena.org/Publications/2020/Dec/Innovation-Outlook-Ocean-Energy-Technologies.

Jenne, D. S., Y.-H. Yu, and V. Neary. 2015. "Levelized Cost of Energy Analysis of Marine and Hydrokinetic Reference Models." Presented at the 3rd Marine Energy Technology Symposium (METS 2015) in Washington, D.C., on April 27–29, 2015. Golden, CO: National Renewable Energy Laboratory. NREL/CP-5000-64013. https://www.nlr.gov/docs/fy15osti/64013.pdf.

Kilcher, Levi, Michelle Fogarty, and Michael Lawson. 2021. *Marine Energy in the United States: An Overview of Opportunities*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5700-78773. https://www.nlr.gov/docs/fy21osti/78773.pdf.

Lee, Susan, Vida Strong, David Anning, Nicole Buecker, Chris Flanary, Grace Chang, Erica Escajeda, Sharon Kramer, and Danielle Mullany. 2025. *Sea Space and Least Conflict Areas for Wave and Tidal Energy*. California Energy Commission. Publication Number: CEC-700-2025-004. Available at https://www.energy.ca.gov/publications/2025/sea-space-analysis-wave-and-tidal-energy.

Magagna, Davide, Riccardo Monfardini, and Andreas Uihlein. 2016. *JRC Ocean Energy Status Report: 2016 Edition*. Luxembourg: European Commission, Joint Research Centre. JRC104799. Available for download at https://www.researchgate.net/publication/316188955_JRC_Ocean_Energy_Status_Report_2016_Edition.

Magagna, Davide. 2019. *Ocean Energy Technology Development Report*. Luxembourg: European Commission, Joint Research Centre. JRC118296. Available at https://publications.jrc.ec.europa.eu/repository/handle/JRC118296.

Maine Public Utilities Commission. n.d. "Net Energy Billing." Accessed July 22, 2024. https://www.maine.gov/mpuc/regulated-utilities/electricity/neb.

Maksumic, Zerina. 2024. "Italy To Launch Offshore Renewable Energy Contract for Difference Auction." *Offshore Energy*. June 5, 2024. https://www.offshore-energy.biz/italy-to-launch-offshore-renewable-energy-contract-for-difference-auction/.

Marine Energy Wales. 2024. *State of the Sector 2024*. Pembroke Dock, Wales: Marine Energy Wales. https://www.marineenergywales.co.uk/wp-content/uploads/2024/07/MEW-2024-State-Of-The-Sector.pdf.

Meng, Jing, Rupert Way, Elena Verdolini, and Laura Díaz Anadón. 2021. "Comparing Expert Elicitation and Model-Based Probabilistic Technology Cost Forecasts for the Energy Transition." *Proceedings of the National Academy of Sciences* 118(27): e1917165118. https://doi.org/10.1073/pnas.1917165118.

Milne, Chris. 2020. "Demystifying the Cost of Tidal Energy." Orbital Marine Power. https://www.orbitalmarine.com/demystifying-the-cost-of-tidal-energy/.

National Hydropower Association. 2024. *Inflation Reduction Act of 2022 Handbook on Federal Tax Credits*. https://hydro.org/wp-content/uploads/2024/09/NHA-Handbook_2024-Edition.pdf.

National Hydropower Association Marine Energy Council. 2021. *Commercialization Strategy for Marine Energy 2021*. Washington, DC: National Hydropower Association. https://www.hydro.org/wp-content/uploads/2021/04/NHA_MEC_Commercialization_Strategy_Marine_Energy.pdf.

National Hydropower Association Marine Energy Council (NHA-MEC). 2024. *Position Paper 3: Marine Energy Priorities*. Washington, DC: National Hydropower Association. https://www.hydro.org/wp-content/uploads/2024/07/POSITION-PAPER-2024-Final-Edition-Marine-Energy-Priorities-07-8-24.pdf.

Neary, Vincent, Michael Lawson, Mirko Previsic, Andrea Copping, Kathleen Hallett, Alison LaBonte, Jeff Rieks, and Dianne Murray. 2014. "Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies." Presented at the 2nd Marine Energy Technology Symposium (METS2014) in Seattle, WA, April 15–18, 2014. SAND2014-3561C. https://www.osti.gov/servlets/purl/1143279.

Nova Scotia Utility and Review Board. 2013. Decision 2013 NSUARB 214. https://www.canlii.org/en/ns/nsuarb/doc/2013/2013nsuarb214/2013nsuarb214.pdf.

Ocean Energy Europe. 2024. *Ocean Energy Stats & Trends 2023*. Brussels, Belgium: Ocean Energy Europe. https://www.oceanenergy-europe.eu/wp-content/uploads/2024/05/Ocean-Energy-Stats-and-Trends-2023.pdf.

Ocean Energy Systems (OES). 2023. *Ocean Energy and Net Zero: An International Roadmap To Develop 300GW of Ocean Energy by 2050*. Lisbon, Portugal: Technology Collaboration Programme on Ocean Energy Systems. https://www.ocean-energy-systems.org/publications/oes-documents/market-policy-/document/ocean-energy-and-net-zero-an-international-roadmap-to-develop-300gw-of-ocean-energy-by-2050/.

Ocean Energy Systems (OES). 2024. *Annual Report: An Overview of Ocean Energy Activities in 2023*. Lisbon, Portugal: Technology Collaboration Programme on Ocean Energy Systems. https://www.ocean-energy-systems.org/publications/oes-annual-reports/document/oes-annual-report-2023/.

Ocean Energy Systems (OES). n.d. "Canada: Supporting Policies for Ocean Energy." Accessed July 17, 2024. https://www.ocean-energy-systems.org/ocean-energy-in-the-world/canada/.

Offshore Renewable Energy (ORE) Catapult. 2018. *Tidal Stream and Wave Energy Cost Reduction and Industrial Benefit*. Swindon, England: Innovate U.K. https://cms.ore.catapult.org.uk/wp-content/uploads/2018/11/Tidal-Stream-and-Wave-Energy-Cost-Reduction-and-Industrial-Benefit.pdf.

Offshore Renewable Energy (ORE) Catapult. 2024. *Tidal Stream Technology Roadmap*. Swindon, England: Innovate U.K. https://cms.ore.catapult.org.uk/wp-content/uploads/2024/03/ORE-Catapult-Tidal-stream-roadmap-report-2024.pdf.

Power Technology Staff. 2023. "France Approves €65M for FloWatt Tidal Energy Project." *Power Technology*. July 10, 2023. https://www.power-technology.com/news/france-funding-tidal-project/.

Proteus Marine Renewables. 2024. "Independent Report Validates AR3000 Cost of Energy Reduction!" https://proteusmr.com/2024/10/04/independent-report-validates-ar3000-cost-of-energy-reduction/.

Tapoglou, E., A. Georgakaki, S. Letout, A. Kuokkanen, A. Mountraki, E. Ince, D. Shtjefni, G. Joanny Ordonez, O. Eulaerts, M. and Grabowska. 2022. *Clean Energy Technology Observatory: Ocean Energy in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains, and Markets*. Luxembourg: Publications Office of the European Union. JRC130617. https://publications.jrc.ec.europa.eu/repository/handle/JRC130617.

Têtu, Amélie, and Julia Fernandez Chozas. 2021. "A Proposed Guidance for the Economic Assessment of Wave Energy Converters at Early Development Stages." *Energies* 14(15): 4699. https://doi.org/10.3390/en14154699.

U.K. Marine Energy Council. 2024. "The Marine Energy Council's 5 Key Asks of the Next U.K. Government." *U.K. Marine Energy Council*. April 6, 2024. https://www.marineenergycouncil.co.uk/news/marine-energy-council-s-5-key-asks-of-the-next-uk-government.

Verdolini, Elena, Laura Díaz Anadón, Erin Baker, Valentina Bosetti, and Lara Aleluia Reis. 2018. "Future Prospects for Energy Technologies: Insights From Expert Elicitations." *Review of Environmental Economics and Policy* 12(1): 133–153. Available at: https://www.journals.uchicago.edu/doi/full/10.1093/reep/rex028.

Wiser, Ryan, Karen Jenni, Joachim Seel, Erin Baker, Maureen Hand, Eric Lantz, and Aaron Smith. 2016. "Expert Elicitation Survey on Future Wind Energy Costs." *Nature Energy* 1: 16135. https://doi.org/10.1038/nenergy.2016.135.

Wiser, Ryan, Joseph Rand, Joachim Seel, Philipp Beiter, Erin Baker, Eric Lantz, and Patrick Gilman. 2021. "Expert Elicitation Survey Predicts 37% to 49% Declines in Wind Energy Costs by 2050." *Nature Energy* 6: 555–565. https://doi.org/10.1038/s41560-021-00810-z.

Wong, Pui Wah, Kristofer Grattan, and Henry Jeffrey. 2023. *Ocean Energy and Net Zero: Policy Support for the Cost Effective Delivery of 12GW Wave and Tidal Stream by 2050*. Plymouth, England: Supergen Offshore Renewable Energy Hub. https://www.etipocean.eu/wp-content/uploads/2023/07/FINAL-double-page-Ocean-Energy-and-Net-Zero-Policy-Support-for-the-Cost-Effective-Delivery-of-12GW-Wave-and-Tidal-Stream-by-2050-03.07.23.pdf.

Additional Resources

Mai, Trieu, Matthew Mowers, and Kelly Eurek. 2021. *Competitiveness Metrics for Electricity System Technologies*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-72549. https://www.nlr.gov/docs/fy21osti/72549.pdf.

Ocean Energy Systems. 2019. *Annual Report: An Overview of Ocean Energy Activities in 2018*. https://tethys.pnnl.gov/sites/default/files/publications/oes2018_0.pdf.

Ocean Energy Systems. 2020. *Annual Report: An Overview of Ocean Energy Activities in 2020*. https://tethys-engineering.pnnl.gov/sites/default/files/publications/oes-annual-report-2020.pdf.

SI Ocean. 2013. *Ocean Energy: Cost of Energy and Cost Reduction Opportunities*. https://oceanenergy-sweden.se/wp-content/uploads/2018/03/130501-si-ocean-cost-of-energy-report.pdf.

Appendix A. Tidal Energy LCOE Elicitation Data

Study data are provided in each table organized by respondent and scenario. The minimum, maximum, mean, standard deviation (SD), and median values of the dataset are estimated for each scenario.

Table A-1. LCOE Estimates by Respondent for All Scenarios

	LCOE 2022 ($/kWh)	Year LCOE Reaches $0.20/kWh Conservative	Year LCOE Reaches $0.20/kWh Optimistic	LCOE 2050 Conservative ($/kWh)	LCOE 2050 Optimistic ($/kWh)
Respondent 1	0.50	2045	2035	0.18	0.15
Respondent 2	0.52	2040	2032	0.30	0.12
Respondent 3	0.30	2026	2045	0.35	0.25
Respondent 4	0.30	2032	2028	0.08	0.05
Respondent 5	0.40	2040	2033	0.15	0.10
Respondent 6	0.28	2035	2030	0.15	0.10
Respondent 7	0.34	2035	2028	0.20	0.12
Respondent 8	0.37	2031	2028	0.09	0.05
Respondent 9	0.35	2045	2035	0.16	0.12
Respondent 10	0.25	2032	2030	0.16	0.09
Respondent 11	0.20	2027	2028	0.09	0.05
Respondent 12	0.28	2034	2032	0.07	0.04
Respondent 13	0.53	2040	2035	0.18	0.13
Min	0.20	2026	2028	0.07	0.04
Max	0.53	2045	2045	0.35	0.25
Mean	0.36	2036	2032	0.17	0.11
SD	0.11	6 years	5 years	0.08	0.06
Median	0.34	2035	2032	0.16	0.10

Table A-2. Capacity Factor (CF) Estimates by Respondent for All Scenarios

	CF 2022 (%)	CF for Year LCOE Reaches $0.20/kWh Conservative (%)	CF for Year LCOE Reaches $0.20/kWh Optimistic (%)	CF 2050 Conservative (%)	CF 2050 Optimistic (%)
Respondent 1	35	30	40	30	40
Respondent 2	20	25	40	30	50
Respondent 3	35	35	45	45	45
Respondent 4	32	32	35	40	42
Respondent 5	35	38	40	40	50
Respondent 6	30	30	35	35	40
Respondent 7	35	45	57	45	59
Respondent 8	37	39	42	43	47
Respondent 9	30	25	30	25	30
Respondent 10	34	30	35	35	42
Respondent 11	50	40	70	55	30
Respondent 12	34	36	36	38	43
Respondent 13	27	27	28	28	28
Min	20	25	28	25	28
Max	50	45	70	55	59
Mean	33	33	41	38	42
SD	7	6	11	8	9
Median	34	32	40	38	42

Table A-3. Rated Power (RP) Estimates by Respondent for All Scenarios

	RP 2022 (MW)	RP for Year LCOE Reaches \$0.20/kWh Conservative (MW)	RP for Year LCOE Reaches \$0.20/kWh Optimistic (MW)	RP 2050 Conservative (MW)	RP 2050 Optimistic (MW)
Respondent 1	2.0	2.5	5	2.5	5
Respondent 2	2.0	2.2	2.5	2.2	2.5
Respondent 3	0.02	0.02	0.02	0.02	0.02
Respondent 4	2	3.25	3.25	4.5	4.5
Respondent 5	1.5	2	5	4	20
Respondent 6	4	4	4	4	4
Respondent 7	2	2	2	2	2
Respondent 8	0.5	0.5	0.5	0.5	0.5
Respondent 9	1.1	1.3	1.5	1.3	1.5
Respondent 10	1.5	1.5	1.5	1.5	1.5
Respondent 11	0.5	0.5	1	1	2
Respondent 12	1.5	1.5	-	3	4.5
Respondent 13	1.5	1.5	1.8	1.8	1.8
Min	0.02	0.02	0.02	0.02	0.02
Max	4	4	5	4.5	20
Mean	1.55	1.75	2.34	2.18	3.83
SD	0.98	1.11	1.66	1.39	5.11
Median	1.5	1.5	1.9	2	2

Table A-4. Cumulative Global Installed Capacity Estimates by Respondent for All Scenarios

	Installed Capacity 2022 (MW)	Installed Capacity $0.20/kWh Conservative (MW)	Installed Capacity $0.20/kWh Optimistic (MW)	Installed Capacity 2050 Conservative (MW)	Installed Capacity 2050 Optimistic (MW)
Respondent 1	10	5,000	5,000	10,000	50,000
Respondent 2	150	200	200	500	800
Respondent 3	2,000	2,000	2,000	2,000	2,000
Respondent 4	17.5	200	200	5,000	20,000
Respondent 5	1,000	1,000	500	3,000	15,000
Respondent 6	96	96	108	108	120
Respondent 7	3	100	50	50,000	100,000
Respondent 8	4	22.5	17.5	650	1,200
Respondent 9	250	400	2,000	2,000	5,000
Respondent 10	100	200	200	400	600
Respondent 11	2,000	2,000	3,000	4,000	6,000
Respondent 12	40	100	-	6,000	7,000
Respondent 13	40	500	100	1,000	1,000
Min	3	22.5	17.5	108	120
Max	2,000	5,000	5,000	50,000	100,000
Mean	439	909	1,115	6,512	16,055
SD	742	1,409	1,581	13,368	28,710
Median	96	200	200	2,000	5,000

Table A-5. Water Depth Assumptions for All Respondents and Scenarios

	Water Depth 2022 (m)	Water Depth $0.20/kWh Conservative (m)	Water Depth $0.20/kWh Optimistic (m)	Water Depth 2050 Conservative (m)	Water Depth 2050 Optimistic (m)
Respondent 1	30	30	30	30	30
Respondent 2	60	60	60	60	60
Respondent 3	40	40	40	40	40
Respondent 4	40	40	40	50	50
Respondent 5	35	35	45	45	50
Respondent 6	10	10	10	10	10
Respondent 7	50	50	50	50	50
Respondent 8	150	150	150	150	150
Respondent 9	50	40	35	40	30
Respondent 10	80	80	80	80	80
Respondent 11	10	10	20	20	25
Respondent 12	40	40	40	50	50
Respondent 13	45	45	40	45	45
Min	10	10	10	10	10
Max	150	150	150	150	150
Mean	49	48	49	52	52
SD	36	36	35	34	34
Median	40	40	40	45	50

Table A-6. Distance to Shore Assumptions for All Respondents and Scenarios

	Distance to Shore 2022 (km)	Distance to Shore $0.20/kWh Conservative (km)	Distance to Shore $0.20/kWh Optimistic (km)	Distance to Shore 2050 Conservative (km)	Distance to Shore 2050 Optimistic (km)
Respondent 1	10	10	10	10	10
Respondent 2	5	5	2	5	2
Respondent 3	1	1	1	1	1
Respondent 4	5	7.5	7.5	20	20
Respondent 5	2	3.5	3	6	5
Respondent 6	20	20	20	20	20
Respondent 7	6	6	6	6	6
Respondent 8	6	6	6	6	6
Respondent 9	15	10	10	10	10
Respondent 10	10	10	10	10	10
Respondent 11	3	3	3	3	4
Respondent 12	3.5	3.5	3.5	3.5	3.5
Respondent 13	3	3	3	3	3
Min	1	1	1	1	1
Max	20	20	20	20	20
Mean	7	7	7	8	8
SD	6	5	5	6	6
Median	5	6	6	6	6