EU-SCORES
European Scalable Offshore Renewable Energy Sources

European Scalable Offshore Renewable Energy Source (EU-SCORES)

D7.9 LCOE Analysis for baseline project scenarios

Oct 2022

Delivery Date	7th of October 2022
Dissemination Level	Public
Status	Final
Version	V3
Keywords	LCOE, Offshore Wind, Offshore Solar, Wave

Disclaimer

This deliverable reflects only the author's views and the Agency is not responsible for any use that may be made of the information contained therein.

Document Information

Grant Agreement Number	101036457
Project Acronym	EU-SCORES
Work Package	WP1
Related Task(s)	T7.5
Deliverable	D7.9
Title	LCOE Analysis for baseline project scenarios
Author(s)	Exceedence Ltd.
File name	D7.9 LCOE Analysis for baseline project scenario_V3(07/10/2022)

Revision History

Revision	Date	Description	Reviewer
1	31/08/2022	Version 1	WP7 partners
2	30/09/2022	Version 2	Consortium partners
3	07/10/2022	Version 3	Consortium partners

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

Contents

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

Abbreviations

ADE	Annual Delivered Energy
AEP	Annual Energy Production
CAPEX	Capital Expenditure
FOW	Floating Offshore Wind
FPV	Floating Photovoltaics
GW	Gigawatts
IRR	Internal Rate of Return
LCOE	Levelised Cost of Electricity
MW	Megawatts
MWh	Megawatt hour
NPV	Net Present Value
OOE	Oceans of Energy
OPEX	Operational Expenditure
PV	Photovoltaic
WACC	Weighted Average Cost of Capital
WEC	Wave Energy Converter

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

1. Executive Summary

This deliverable, D7.9 LCOE Analysis for baseline project scenarios, aims to present the baseline financial models built in the Exceedence software, ExFin, and exported to a summary report for a range of combined offshore renewable energy projects, based on data provided by the consortium partners and from wider industry information.

This report introduces the metric Levelised Cost of Electricity (LCOE), used by the energy industry as a metric to compare different methods of electricity generation on a comparable basis per kWh or per MWh. LCOE is sensitive to a number of factors such as availability, survivability, affordability, and performance, which can all impact on LCOE either positively or negatively.

This report introduces the Exceedence financial analysis software, ExFin, which is a cloud based standardised techno-financial software tool allowing the user to quickly and intuitively build, analyse and optimise any number of renewable energy projects and then presents them in a sophisticated analysis and comparison dashboard.

This report introduces the baseline LCOE, installed capacities and future targets for offshore wind, distinguishing between fixed and floating wind, offshore floating photovoltaic and wave energy.

A generic fixed offshore wind project has been built using the Exceedence financial analysis software, and a project summary PDF has been generated to show the inputs and resulting outputs of this project. Similar summary PDFs will be created in future deliverables under EU-SCORES for wave, offshore photovoltaic, and combined projects.

A combined visual has also been created to show the different sector LCOE ranges along with plotting the specific targets for the wave energy developer CorPower Ocean and the offshore solar developer Oceans of Energy.

Finally, this report introduces hybrid energy parks and their advantages and challenges.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

2. Introduction to Levelised Cost of Electricity

The Levelised Cost of Electricity (LCOE) is a comparative metric used in the energy industry to assess the relative merits of generation types. The LCOE attempts to compare different methods of electricity generation on a comparable basis per kWh or per MWh. It is the key measure used in comparing different energy projects and is defined as the ratio of total lifetime expenses of the generation facility under analysis, versus the total expected production, and is expressed in terms of the present value equivalent. The 'costs' include all costs such as CAPEX (capital expenditure), OPEX (operational expenditure), commissioning and decommissioning costs etc. For renewable projects, LCOE combines a lot of information into one indicator, including the resource potential, performance and efficiency, availability, finance, discount rate, tax, inflation, revenues etc.

The LCOE equation is:

$$LCOE = \frac{Sum\ of\ Costs\ over\ Lifetime}{Sum\ of\ Electrical\ Energy\ Produced\ over\ Lifetime} = \frac{\sum_{t=1}^{n}\left(\frac{I_t + M_t}{(1+r)^t}\right)}{\sum_{t=1}^{n}\left(\frac{E_t}{(1+r)^t}\right)}$$

where I_t is the initial cost at year t, M_t is the maintenance or operational cost at year t, r is the discount rate, and E_t is the electricity or yield generated at year t.

The LCOE is sensitive to a number of factors that can be divided into four key high-level categories and a number of subcategories, which feed into these, as shown in Figure 1. Each of these categories impact positively or negatively on the LCOE. There are also direct links between some of the sub-headings (links not shown in the diagram) such as a close association between the OPEX and Reliability and Maintainability. Another example is that renewable power sources, such as wave, tidal and wind, are sensitive to their location which will affect the capacity factor and thus the performance. It is therefore important to understand the relationships between these categories and how they impact on LCOE.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

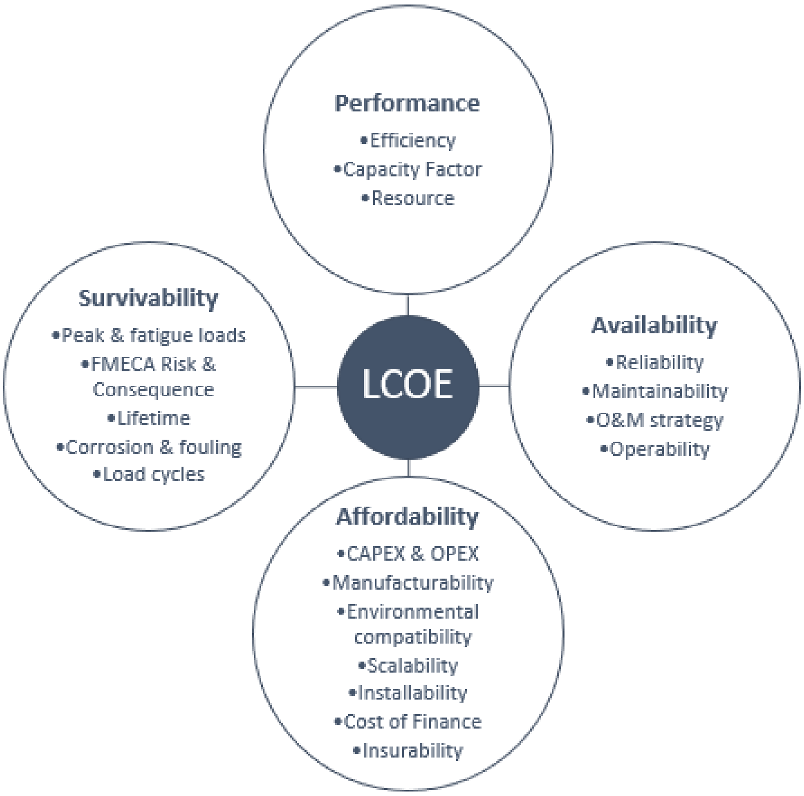


Figure 1 – LCOE and high-level categories and subcategories. Created by Exceedence Ltd © 2019

Furthermore, depreciation rates vary widely by power source: For example, the likely lifetime of a nuclear generating plant will far exceed the lifetime projected for a wave array deployed in the Atlantic. Discount rate is another factor to bear in mind. At its theoretical basis, it is a measure of time value and uncertainty risk. In other words, it is the interest rate used to determine the present value of future cash flows, which in turn helps determine if the future cash flows from a project or investment will be worth more than the capital outlay needed to fund the project or investment in the present. If a company has the necessary information of debt/equity and the respective weighting, the weighted average cost of capital (WACC) can be calculated instead and then used as the discount rate for calculating the Net present value (NPV). For example, a high discount rate implies greater risk and a lower present value of future cash flow and vice versa. As such, the discount rate has a significant impact on the LCOE.

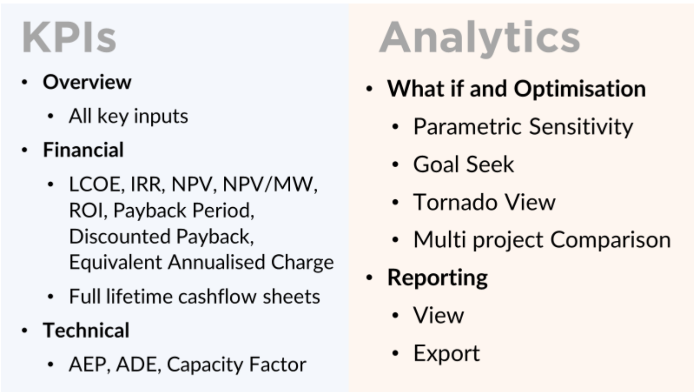
Although the LCOE is the favoured financial indicator when comparing technologies, it is important to note that this indicator should not be used in isolation when determining whether to invest in a project. Other financial metrics should also be considered, such as Net Present Value (NPV) and Internal Rate of

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

Return (IRR). For example, a project with a high LCOE may still have a reasonable IRR due to a high level of tariff or grant support and may therefore still be worthy of investment. Furthermore, the LCOE does not provide information on the quality of the electricity, nor the time value of that electricity source. For example, there are real concerns that regardless of the LCOE cost reduction trajectory seen in offshore wind, the market value of the energy supplied to the grid is under pressure due to possible oversupply[1].

2.1 Introduction to Exceedence Software - ExFin

The Exceedence financial analysis software, named ExFin, is a cloud based standardised techno-financial software tool that allows the user to quickly and intuitively build, analyse and optimise any number of renewable energy projects and then present them in a sophisticated analysis and comparison dashboard. It allows the user to focus on analytics and to identify and reduce risks early on. One of the main appeals of this software is its sensitivity analysis features, which allows the user to quickly assess "what if" questions among other things.



ExFin has been calibrated against a number of existing financial tools including case studies with one of the big four accounting firms. To date, it has been used for prospecting, project development, product development, tariff analysis, test site development, and investment decisions.

Figure 2: KPI's and Analytics that ExFin produces.

It has also been used in consulting projects and tenders for cost benefit analysis of materials, components lifetimes, blade types and locations. The software has an intuitive workflow, illustrated by the flow chart in Figure 3. The technical aspects of the model consist of location/resource and device selection. The financial aspect of

[1] Pennock. S. et al., 2022. Temporal complementarity of marine renewables with wind and solar generation: Implications
for GB system benefits. Applied Energy 319 (2022) 119276

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

the model requires capital expenses (CAPEX), operational expenses (OPEX) and other financial inputs. ExFin then calculates the final results of LCOE, IRR and NPV. At this stage, the analysis module can be used to ask the all-important "what if" questions by conducting a 'goal seek' or examining parametric sensitivities. The different KPI's and analytics ExFin produces is listed in Figure 2.

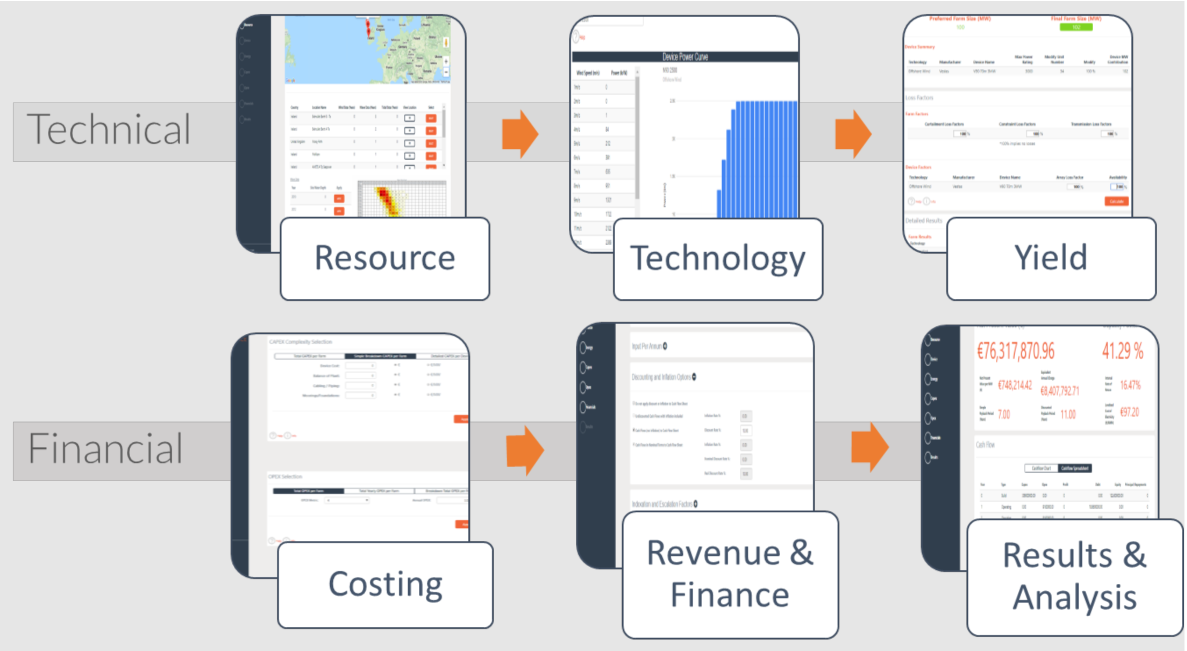


Figure 3 – Flow schematic of ExFin, a techno-financial modelling software.

ExFin contains a database of renewable locations together with technical information on typical devices. The user can add to these databases by uploading their own location or device information. The software uses this information to calculate the amount of energy a particular device will produce at a particular location.

The financial section of the software allows the user to input all the costs associated with planning, installing, commissioning, operating and decommissioning a renewable energy project. By combining the financial information with the energy output data, the Exceedence software produces a cash flow sheet for the entire duration of a project. It returns financial indicators such as NPV, LCOE, IRR, and Payback Period. With this information, users can explore which technologies and locations are the most promising in terms of future renewable deployments. A screen shot of the Project Dashboard in ExFin is shown in Figure 4.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

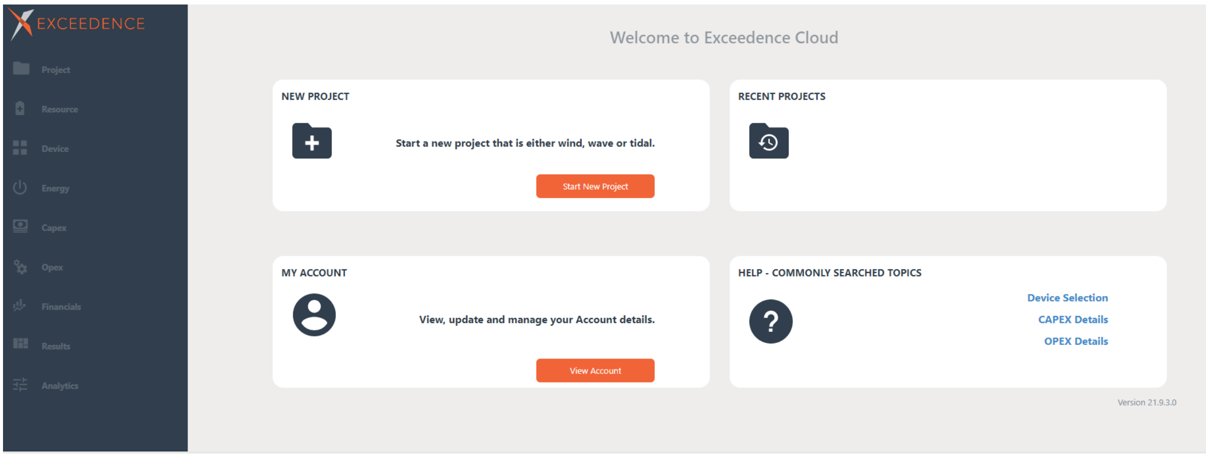


Figure 4 - Screenshot of the ExFin dashboard.

Currently ExFin allows for four different types of project configurations: **off-shore/on-shore wind farms, tidal farm, wave farm, or a combination of any of the first three technologies.** The user needs to input certain project data such as, the desired farm size, the currency, operating years, specify any predevelopment years, and decommissioning years. Next, the model requires both resource data (hourly or annual summary) as well as device data. The software contains a database for both resource data in addition to a database of leading wind, wave and tidal devices. The user also has the option to add their own databases. Based on the initial input data, ExFin calculates the energy output of the project. Changes to the final farm size can be made now in addition to accounting for loss factors such as availability and transmission losses.

Next, the user will be prompted to enter the financial data into the software including CAPEX, OPEX, Salvage, Decommissioning, Revenue, Discounting Inflation, Indexation and Escalation Factors, Debt/Equity, Tax, and Depreciation.

The software allows the user to enter both CAPEX and OPEX at three different levels of detail: Total CAPEX per farm, Simple breakdown of Total CAPEX per farm, or a Detailed breakdown of CAPEX per device, Total OPEX per farm, TOTAL yearly OPEX per farm, or Breakdown total OPEX per farm. A screenshot of the CAPEX entered for an example device can be found in Figure 5.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

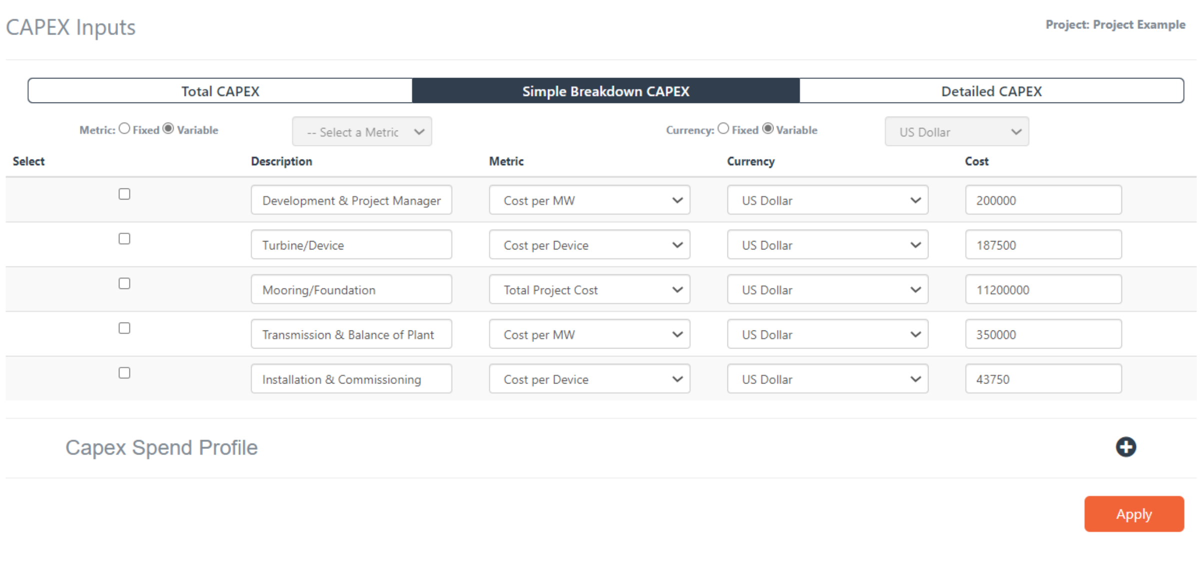


Figure 5 - Screenshot of CAPEX for an example device entered into ExFin.

ExFin provides both energy results and financial project results. Energy results are provided as Device Capacity Factors, Farm Annual Energy Production, Farm Actual Energy Capture, and Farm Annual Delivery Energy. Financial project results are provided as NPV and NPV per MW, IRR, LCOE, Simple Payback Period, Discounted Payback Period, and Equivalent Annual Charge. A screenshot of an example project calculated using the software can be found in Figure 6.

The results can be viewed graphically from the Resource, Device, CAPEX, and OPEX modules. Another function is that all results can be exported to EXCEL, which can in turn be used to build bank ready financial spreadsheets.

Once ExFin has calculated the results using the preferred project and financial data, the user can conduct sensitivity analysis on the project's input parameters. This is a function that allows users to assess the impact of changes on the project results. The user can either fine tune the project results by adjusting each input to establish the project configuration that produces the best return, or perform a Goal Seek on the necessary value of inputs required to achieve target results. A screenshot of the fine-tuning analysis can be found in Figure 7.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

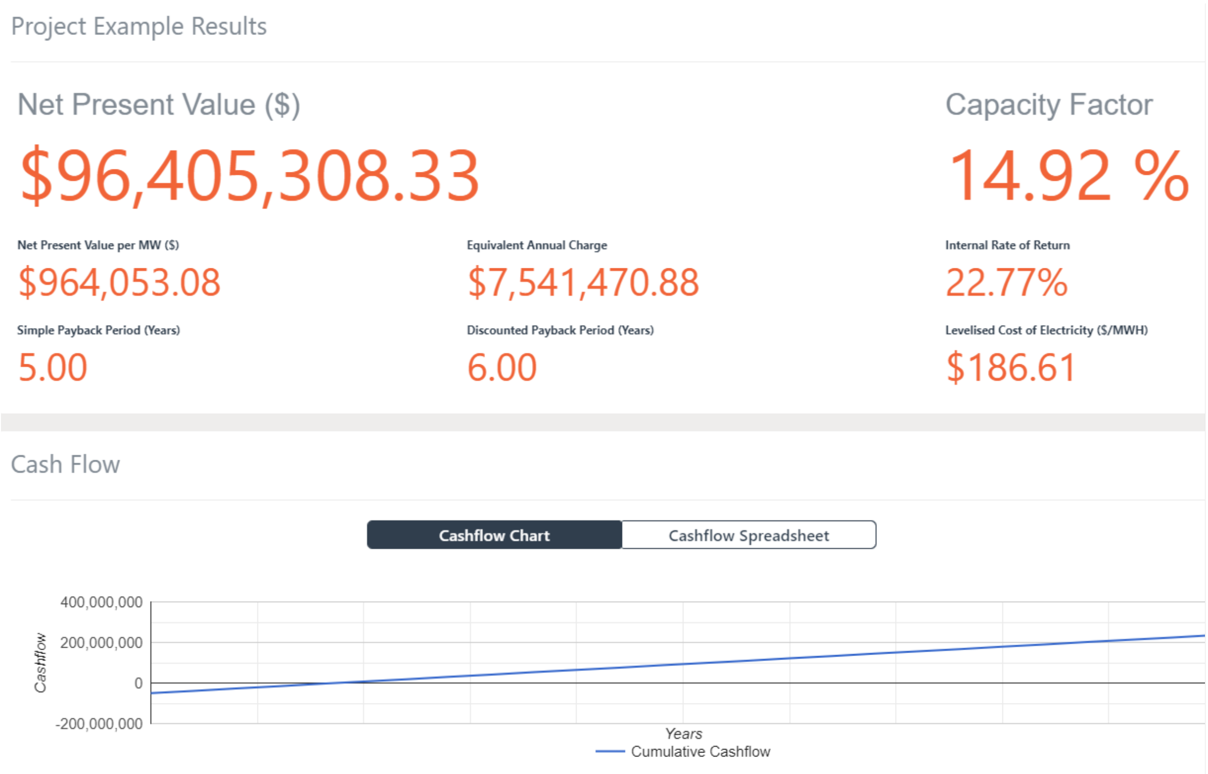


Figure 6 - Screenshot of the project results page in ExFin.

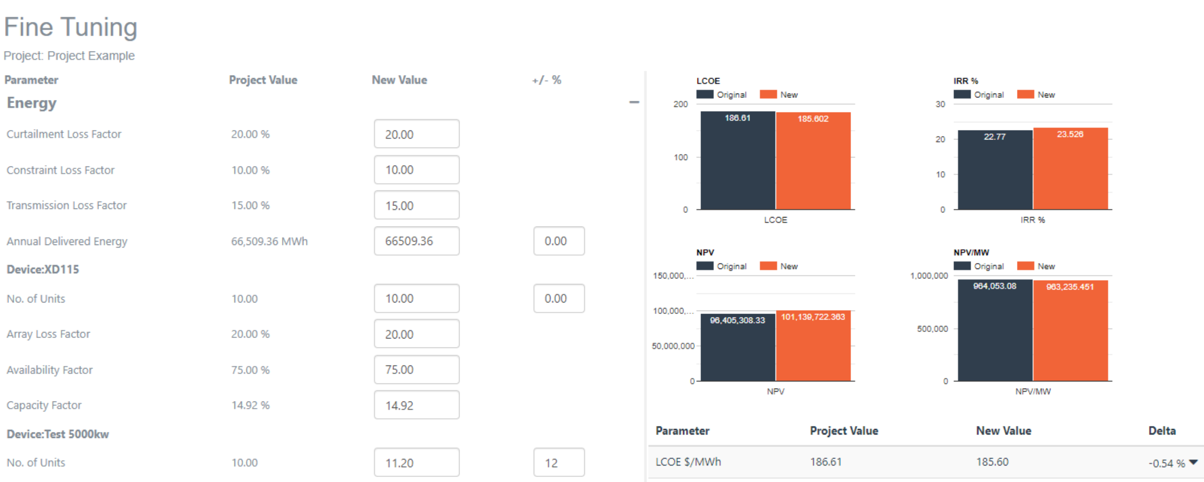


Figure 7 - Screenshot of the fine-tuning analysis tool in ExFin.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

3. Sector Levelised Cost of Electricity

This chapter presents a snap shot of the main three energy sectors in focus within the EU-SCORES project: offshore wind, offshore solar, and wave energy. Each of the individual energy sectors are at different stages of commercialisation, which means that they also have different average LCOE ranges and currently existing installed capacities. The next three sections briefly describe the state-of-the art of each sector, estimated future LCOE and installed capacity projections, along with any specific targets the sector is aiming to achieve.

In the offshore wind sector section, an example project has also been built for offshore wind using ExFin. A project summary PDF has been generated to show the results of the offshore wind projects inputs and resulting outputs. Project summary PDF’s will also be generated for wave and offshore solar projects. However, the PDF’s will be produced in a future EU-SCORES project deliverable, i.e., D7.10 in month 43. The work on the project inputs for the models and subsequent output LCOE, IRR and NPV for wave and offshore solar is underway and is expected to be presented in the final year of the project.

The final section in this chapter summarises the presented information through a combined view of the offshore renewable technologies LCOE ranges and learning rates.

3.1 Offshore Wind Sector

The offshore wind sector has been steadily growing since the early 2000’s and has advanced beyond the demonstration phase and into commercialisation. The sector is comprised of fixed and floating offshore wind. Fixed offshore wind is currently the more mature technology, with fast growing supply chains, and the experience gained from learning by doing has caused costs to fall worldwide. This in turn, with heightened competition, has led to global deployment of fixed offshore wind installations. As the climate crisis continues to be at the forefront of global issues, more countries are investigating what their own climate can provide in terms of renewable resources.

As a consequence of more commercial projects being deployed in fixed offshore wind, the LCOE within this sector has seen more reductions in 2020, with a 16% reduction from 2019 LCOE figures[2]. The average LCOE in 2020 for bottom-fixed

[2] Musial et al., 2020. 2019 Offshore Wind Technology Data Update.

This project has received funding from the Europeans Union’s Horizon 2020 research & innovation programme under grant agreement number 101036457.

offshore wind projects ranged between 66 EUR per MWh to 106 EUR per MWh, with an average of 86 EUR per MWh[3,4].

The cumulative installed capacity of total offshore wind has grown globally from 3GW in 2010 to almost 34GW[5], in 2020. This is an increase of 1125% in just a decade. In 2021, global offshore wind is estimated to have grown further to a total capacity of 56GW[6]. Europe is the leader in offshore wind installations, with more than half of the cumulative deployment installed, a figure of 28.3 GW[7]. Globally, since 2021, China is the leading country for cumulative installed capacity with approximately 26GW, followed by the UK with 12.7GW.

Offshore wind is estimated to have a theoretical potential of approximately 22,000GW in Europe alone, with an estimated value of 8,000GW in fixed offshore wind and 14,000GW in floating offshore wind potential, where water depths are 60m or more[8]. This limits the potential capacity achieved by bottom-fixed offshore wind, where deployment can largely only be accomplished in waters of less than 60m. This estimation suggests that project developers will likely need to consider deeper water installations in order to capture this potential, either through innovation in bottom fixed foundations or through floating offshore wind.

Floating offshore wind (FOW) has the ability to surpass bottom-fixed in terms of installed capacity and project farm sizes, it is estimated to reach commercial scale deployment with 7GW deployed in Europe alone by 2030[9]. The total global installed capacity of floating offshore wind in 2020 was 75MW[3,10]. In 2021, global FOW is estimated to have grown further to a total capacity of 123MW[11]. The current average LCOE for FOW is estimated to 149 EUR per MWh, and by 2030 is expected to drop to an average of 70 EUR per MWh[3,4,12]. Demonstration projects are quickly progressing to pre-commercial with a number of enabling technology improvements, and can no longer be seen as emerging technology[13].

---

[3] DOE, 2021. Offshore Wind Outlook Report.
[4] ETIP, 2021. Getting Fit for 55 and set for 2050.
[5] IRENA, 2021. Renewable Capacity Statistics.
[6] GWEC, 2022. Global Wind Report 2022.
[7] WindEurope, 2022. Wind Energy in Europe: 2021 Statistics and the Outlook for 2022 to 2026.
[8] The World Bank, 15/03/2022, 'Global Offshore Wind Technical Potential' https://datacatalog.worldbank.org/search/dataset/0037787 Date Accessed: 23/09/2022.
[9] OREAC, 2020. The Power of Our Ocean.
[10] WindEurope, 2021. Offshore Wind in Europe: Key Trends and Statistics 2020.
[11] DOE, 2022. Offshore Wind Market Report.
[12] DNV GL, 2020. Floating Wind: The Power to Commercialize.
[13] Wind Energy Ireland, 2021. Revolution – A Vision for Irish Floating Wind Energy.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

The Exceedence financial analysis software, ExFin, can produce a number of different outputs, one of which is a "project summary" in PDF format. This output allows the user to quickly view and share the inputs and resulting outputs of that particular project set-up as modelled in ExFin. A generic fixed offshore wind projects has been built, based on the most recent publicly available information that gives a current average LCOE baseline of 86 EUR per MWh. The wind data is open-source data from the SEAI wind atlas[14], which is modelled data from 2006 at 50m height. The turbine is a generic 10MW turbine modelled by DTU. The cost and project input data are based on the information provided by BVGA[15].

[14] SEAI wind atlas, https://gis.seai.ie/wind/

[15] BVGA, 2019. Guide to an Offshore Wind Farm.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

EXCEEDENCE

Generated by **Exceedence Finance**

01 September 2022

Version: [appversion]

Project Name: **EU-SCORES_Fixed Offshore Wind**

Project Summary

Main Project Details		Resource Details	
Farm Technology	Fixed Offshore Wind	**Country**	Ireland
Final Farm Size (MW)	1000 MW	**Location Name**	Celtic Sea Tramore
Operating Years	27 year(s)	**Data Year(s)**	2005
Pre-Development Years	0 year(s)	**Water Depth (m)**	35 m
Decommissioning Years	1 year(s)	**Measuring Height (m)**	50 m
Project Currency	EUR - Euro [€]	**Comments**	

Device Details

#	Renewable Technology	Manufacturer	Device Name	Deployment Depth/Height (m)	Power Rating (kW)	Capacity Factor (%)
1	Fixed Offshore Wind	DTU	Generic @100m	100m	10000 kW	49.78 %

Farm Energy Output Results

Farm Annual Energy Production (MWh)	4,449,345 MWh
Farm Actual Energy Capture (MWh)	4,360,358 MWh
Farm Annual Delivered Energy (MWh)	4,229,547 MWh

Cost Information

	EUR [€]	EUR [€]/MW
CAPEX	€ 3,300,000,000	€ 3,300,000 / MW
OPEX	€ 87,000,000	€ 87,000 / MW
Decommissioning	€ 330,000,000	€ 330,000 / MW

Financial Inputs

Total Revenue Rate (EUR [€]/MWh)	€ 70.00 / MWh
Discount Rate (%)	6 %
Inflation Rate (%)	2 %
Debt/Equity Ratio	80 / 20
Borrowing Rate (%)	6.00 %
Tax Rate (%)	0.00 %
Revenue Indexation Rate (%)	0 %
Opex Escalation Rate (%)	0 %
Borrowing Term	15 year(s)

Results

Net Present Value [NPV] (EUR [€])	€ 71,012,456.61
Internal Rate of Return [IRR] (%)	6.41 %
Levelised Cost of Electricity [LCOE] (EUR [€]/MWh)	€ 86.02 / MWh
Simple Payback Period	19.00 year(s)
Discounted Payback Period	25.00 year(s)
Equivalent Annual Charge (EUR [€])	€ 5,375,441.73
Farm Capacity Factor (%)	49.78 %

Figure 8: Example project summary of a fixed offshore wind project at the current average baseline LCOE, generated by ExFin.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

3.2 Offshore Solar Sector

The global cumulative installed capacity of Solar PV, totaled approximately 942GW[16] in 2021, which included an estimated 3GW of installed in-land floating PV (FPV) [17] and an estimated 0.3MW of offshore solar [18].

Distinction is made between in-land FPV and offshore solar, which are sometimes confused with each other. These are not comparable technologies and are deployed in very different environments. Offshore solar designs are always designed to be floating, as fixed bottom is unrealistic in the offshore environment, and are designed for a significant wave height of 4m waves. As information on offshore solar is limited in publicly available information, it is interesting to understand the current development and LCOE of in-land FPV (and ground mounted PV) as offshore solar will likely follow a similar trajectory.

Although in-land FPV is still considered a niche market, with 0.32% of the total installed PV market currently, it is expected that in-land FPV will achieve an average growth rate of 20%[19] in the coming five years, which could see an additional 14GW cumulative deployed capacity. In fact, a recent study[20] has shown that the technical potential for in-land FPV when integrated with hydropower reservoirs alone, could potentially reach a capacity of 5,700GW and an estimated 8,000TWh of electricity. In early 2021, the largest in-land FPV[16] in operation was a 181 MW plant off the west coast of Chinese Taipei.

There is considerable global interest with more than 60 countries actively pursuing in-land FPV projects. In 2018, China was the market leader accounting for 73%[21] of the installed projects globally. Adding Japan, Korea, and Taiwan into the mix, it is clear to see that Asia is driving demand. As a comparison, ground mounted PV reached the 1GW cumulative deployment milestone in 2000[22], whereas in-land FPV reached this milestone in 2018.

---

[16] IEA, 2022. Snapshot of Global PV Markets 2022.

[17] Ren21, 2022. Renewables 2021 Global Status Report.

[18] Oceans of Energy, 01/09/2022, EU-SCORES, https://oceansofenergy.blue/2021/09/01/eu-scores-project-aims-to-deliver-world-first-bankable-hybrid-offshore-marine-energy-parks/ Date Accessed: 29/09/2022.

[19] PV Magazine. 2020. Floating solar PV gains global momentum. Published online 22nd September 2020. https://www.pv-magazine.com/2020/09/22/floating-solar-pv-gains-global-momentum/

[20] Farfan and Breyer, 2018. Combining Floating Solar Photovoltaic Power Plants and Hydropower Reservoirs: A Virtual Battery of Great Global Potential.

[21] World Bank Group, ESMAP and SERIS. 2019. “Where Sun Meets Water: Floating Solar Market Report”.

[22] Ren21. 2019. Renewables 2019 Global Status Report.

This project has received funding from the Europeans Union’s Horizon 2020 research & innovation programme under grant agreement number 101036457.

Regardless of rapid advancements that showcase large cost reductions, offshore solar is currently less established than in-land FPV, which in turn is less established than ground mounted PV. Both offshore solar and in-land FPV are starting to gain traction, with drivers[16] such as grid congestion on land, land scarcity and high costs in many places. Design innovations and improvements in efficiency are also helping to reduce costs, in spite of the additional challenges associated with currents, waves and salt water.

The advantages of offshore solar are particularly strong, these include:

- The possible integration of offshore solar with offshore wind farms, in terms of spatial planning, this can lead to no rental costs.
- Connections at offshore wind grid infrastructure, with no additional investments required, leading to minimal curtailment losses.
- Increasing the utilization of other offshore infrastructure, such as the possible offshore wind energy conversion to hydrogen (more full-load hours per year for expensive electrolysers).
- At sites where offshore wind is particularly expensive, i.e., areas with high-water depth, further distance to shore, limited wind climate, but where advantages of moving renewables offshore are large.

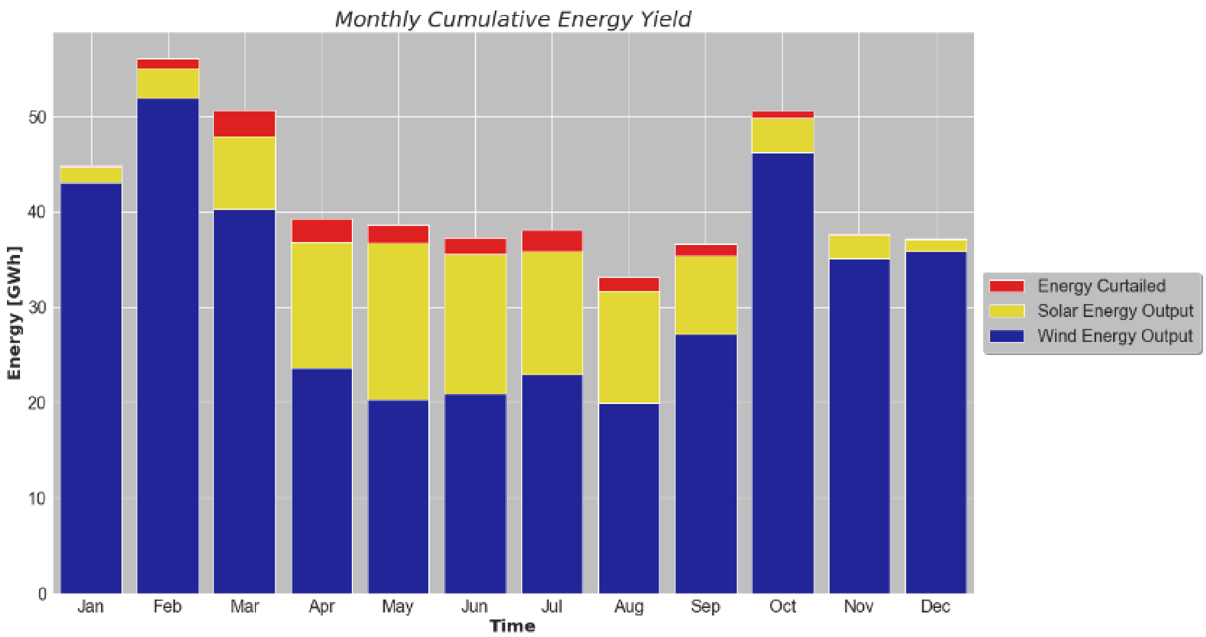


Figure 9: OOE simulation results of 100 MW Export System with 100 MW offshore wind + 100 MW offshore solar installed, at North Sea site per month in 2020.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

In 2020, IRENA[23] published global weighted averages for total installed costs, capacity factors and LCOE for the years spanning 2010 to 2019. Although these numbers are for ground mounted PV, the general trends show a clear reduction in installment costs, and increasing capacity factors, which in turn result in decreasing LCOE. Taking a closer look at LCOE, back in 2010, the average global LCOE for PV was 342 EUR per MWh, whereas in 2019 it had dropped to 61 EUR[24] per MWh. Interestingly, according to the World Bank Group[25] LCOE of in-land FPV installations are already comparable to that of ground mounted PV. The reasoning is that although in-land FPV have slightly higher capital expenditure (CAPEX) (EUR per MW) chiefly due to requiring floats, mooring, and more resilient electrical components, higher yields are expected as opposed to ground mounted PV (between +5% to +10% more) thus balancing out the increase in CAPEX.

LCOE estimates on offshore solar is limited by a lag of data. Current offshore solar LCOE is estimated to be 354 EUR per MWh[26,27] in industry reports. Oceans of Energy (OOE), have estimated their LCOE based on learning rates experienced and scaling factors in system sizes. The models indicate the LCOE to drop below 120 to 150 EUR per MWh once 4MW of global installed capacity has been reached, which is expected to occur during the EU-SCORES project in 2023. Estimates fall even further once more projects come online and by 2025, LCOE is projected to advance to less than 100 EUR per MWh. By 2030 this number will fall even further to below 50 EUR per MWh. The plot of the OOE LCOE model, projected until 2030, is illustrated in Figure 10. This figure includes multiple LCOE results for 'North Sea in windfarms' and for 'Southern-EU islands' configurations. The plots for 'North Sea in windfarms' are focused on large projects between 100 to 10,000MW. In the 'Southern-EU islands' market project sizes are expected to be smaller due to lower energy consumption at islands. The calculations are based on a conservative scaling scenario (4.2GW in 2030).

---

[23] IRENA. 2020. Power Generation Costs 2019.
[24] Average exchange rate 2019 USD = 0.8931 EUR
[25] World Bank Group, ESMAP and SERIS, 2019. "Where Sun Meets Water: Floating Solar Market Report".
[26] Bosh Solar, 06/01/2021, 'Offshore Floating Solar PV May Reach Maturity in 2030', https://www.bosch-solar.com/news/offshore-floating-solar-pv-may-reach-maturity-in-2030.html Date Accessed: 08/08/2022.
[27] Solar Edition, 04/01/2021, 'Offshore solar panels have the potential to reach the ground-mounted PVs in terms of LCOE', https://solaredition.com/offshore-solar-panels-have-the-potential-to-reach-the-ground-mounted-pvs-in-terms-of-lcoe/ Date Accessed: 08/08/2022.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

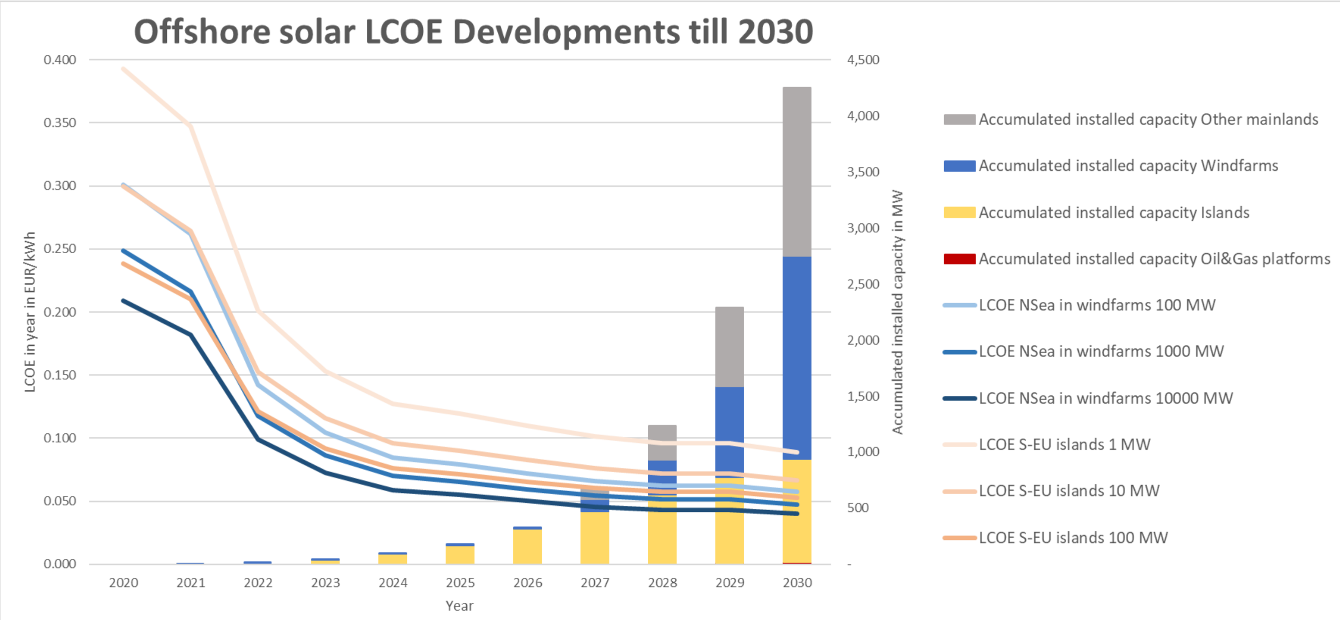


Figure 10: Oceans of Energy LCOE model - Plot for cost reduction developments till 2030. Assumptions based on 2020 prices (pre-Ukraine crisis).

The cost models predict that the total projects lifetime costs of a 1000MW offshore solar project integrated within a North Sea wind farm will drop rapidly. This makes offshore solar a fully economically viable source of energy.

Estimated costs are:

- 2030: lifetime cost of 0.849 MLN/MW and LCOE of 46 EUR/MWh
- 2040: lifetime cost of 0.515 MLN/MW and LCOE of 28 EUR/MWh
- 2050: lifetime cost of 0.458 MLN/MW and LCOE of 24 EUR/MWh

3.3 Wave Energy Sector

In 2020, the total installed capacity from Ocean Energy was 534.7MW worldwide[28]. Of this, more than 90%, was represented by three tidal barrage facilities: Sihwa (258MW) in Korea republic, La Rance (220MW) in France, and Annapolis Royal (20MW) in Canada. When excluding tidal barrage facilities, Europe is leading the way in ocean energy development and deployment. Scotland[29] in particular continues to be the centre for the majority of activity.

There are a range of projections for the potential growth of the ocean energy sector in Europe and globally. Ocean Energy Europe (OEE) estimates a high and low

[28] IRENA, 2020. Innovation Outlook: Ocean Energy Technologies.
[29] Ren21, 2019. Renewables 2019 Global Status Report.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

deployment scenario[30] for wave energy by 2030, between 178MW to 494MW of wave energy devices installed in European waters. They[31] further estimate that under favourable regulatory and economic conditions, ocean energy can supply 10% of Europe's electricity demand by 2050, equating to an estimated 100GW of installed capacity, and generating approximately 350TWh per annum. It is expected that, with this level of roll out, the market will be worth an estimated €53bn annually in 2050. In contrast, the European Commission[32] expects 1GW of ocean energy technologies installed by 2030, and 40GW by 2050.

The cumulative Wave Energy Converter (WEC) device deployment has reached 140 units in 2020, with one new WEC being deployed during that same year. However, since 2019, the wave energy sector has seen other regions overtake Europe in terms of annual installed capacity. This is in most part due to both China and the USA devoting more resources to the sector. Europe has had a cumulative deployment of 12MW of which 1.1MW is still in the water. 10.9MW has been decommissioned following successful completion of testing programmes. The next phase will see deployment of new full-scale devices and first wave energy pilot farms. As of 2021, the global cumulative installed capacity of wave energy is now 24.7MW[33].

It must be noted that several of the US and Chinese companies are also carrying out development activities in the EU. A current trend worth noting, is that WEC developers are pursuing dual-purpose opportunities, such as electricity and freshwater production in response to increasing demand from islands. These types of market opportunities are becoming increasingly important for WEC developers alongside mainstream power production.

The Set-Plan[34] sets the target for wave energy to reach an LCOE of 200 EUR per MWh by 2025, 150 EUR per MWh by 2030 and 100 EUR per MWh by 2035. It must be noted that these expected cost reductions are driven by cumulative installed capacity (economies of scale) of WEC's and not by the passing of time. ORE-Catapult[35] shows prototype devices calculating to LCOE values in excess of 300 EUR per MWh, although they admit that these findings are from sparse available data. Through cost reductions, such as initial acceleration reductions, learning by doing and reduction in cost of capital, ORE-Catapult foresee LCOE in the wave

[30] Ocean Energy Europe, ETIP Ocean, 2021. 2030 Ocean Energy Vision.
[31] Ocean Energy Forum, 2016. Ocean Energy Strategic Roadmap 2016, building ocean energy for Europe.
[32] European Commission, 2020. An EU Strategy to harness the potential of offshore renewable energy for a climate.
[33] Ocean Energy Europe, 2022. Ocean Energy Key Trends and Statistics 2021.
[34] Working Group Ocean Energy, 2018. Set-Plan Ocean Energy - Implementation Plan, Final March 2018 Adopted by Set-Plan steering committee.
[35] ORE Catapult, 2018. Tidal Stream and Wave Energy Cost Reduction and Industrial Benefits.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

energy sector dropping significantly in line with tidal stream but with a lag of approximately 10 years. They estimated tidal stream LCOE reaching 171 EUR per MWh once 100MW of tidal stream cumulative deployment has been installed. This will reduce the sectors LCOE to 103 EUR per MWh at 1GW, and to 92 EUR per MWh at 2GW cumulative deployment[36]. In other words, dramatic reductions in LCOE will need a combination of development and deployment or 'learning by doing'. SI Ocean[37] applies a learning rate of 12% and a 3% load factor improvement to generate their cost reduction curves.

The OEE / ETIP Ocean 2030 vision paper[38] forecasts a more ambitious LCOE of 110 EUR per MWh by the same year than the The Set-Plan. CorPower Ocean demonstrates a realistic path towards an LCOE by 2030 (Figure 7) that is 50-60% lower than the SET Plan target with adequate commercial roll-out.

CorPower's LCOE is projected to drop to 70 EUR per MWh at 600MW installed, and 30-40 EUR per MWh after 20GW installed.

CorPower Ocean has an extensive LCOE model developed in collaboration with leading actors in the field of wave energy such as WavEC, Inn2Grid, Iberdrola Engineering, and UEDIN within the Wave Boost H2020 project. UEDIN (consortium partner) performed an independent 3rd party validation of CorPower's model against their recognised calculation methodology. The model uses a generation-based approach with bottom-up learning rates set separately for each sub-system contributing to CAPEX, calibrated by volume quotes from suppliers. Key drivers behind the cost-reductions for future generations of the technology include:

- Technology improvements increasing the productivity – higher capacity factor and more AEP per MW:
    - Improved control – towards optimal phase and amplitude in each wave
    - Reduced losses (mechanical and electrical)
- Reliability improvement increasing the availability of the product,

[36] Average exchange rate 1 GBP = 1.1453 EUR, https://www.exchangerates.org.uk/GBP-EUR-spot-exchange-rates-history-2018.html#:~:text=This%20is%20the%20British%20Pound,rate%20in%202018%3A%201.1301%20EUR. Date Accessed: 25/08/2022.
[37] SI Ocean, 2013. Ocean Energy: Cost of Energy and Cost Reduction Opportunities.
[38] Ocean Energy Europe; ETIP Ocean, 2020. Strategic Research and Innovation Agenda for Ocean Energy, 2020.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

- Economies of scale as well as improved (and simplified) design, reducing CAPEX and OPEX,
- Reduced financing cost (WACC) as deployment increase and perceived risks by financers are eliminated,
- Increased asset life, from 20y in early arrays to 25y midterm and later stage 30y
- Increasing farm sizes, reducing project development per MW, electrical infrastructure, and O&M costs.

CorPower's Product Roadmap tracks the key device and farm metrics for reliability, performance, and cost of future device generations, which sets the conditions for LCOE and the profitability of future wave projects:

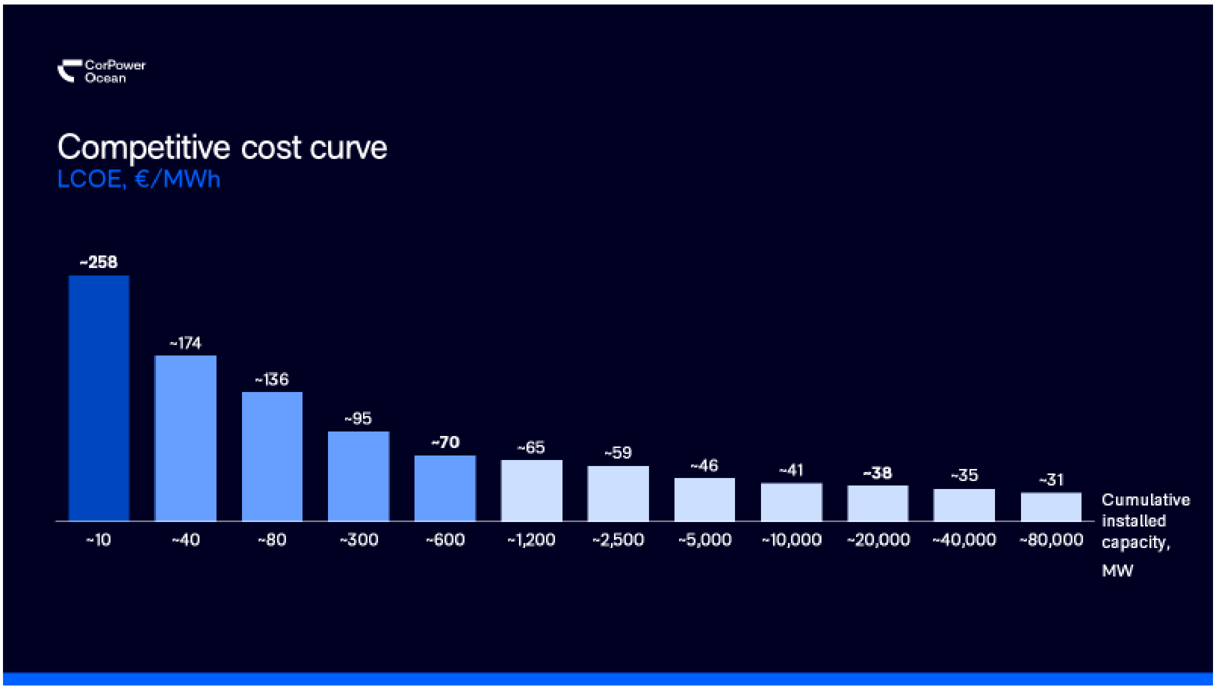


Figure 11 - CorPower's current LCOE model and sales forecast: projection on LCOE vs cumulative installed capacity in the market. Updated as of 10/10/2022.

3.4 Sectoral LCOE Ranges

To combine the LCOE ranges and targets presented in the previous sections, an image has been designed to display the different sector LCOE and global cumulative installed capacity. The purpose of this image is to show current and projected ranges for fixed and floating offshore wind, wave and offshore solar using publicly available reports and respective industry learning rates. By illustrating all the individual sectors into one figure, the reader can clearly see how fast each sector's LCOE is falling, and cumulative deployment figures are increasing, while

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

mapping out CorPower Ocean and Oceans of Energy targeted LCOE ranges from participating in the EU-SCORES project.

This figure is useful for clarity as it puts each technology sector into context relative to the average baseline today as well as comparatively to each other and to the more mature offshore wind sector. It also shows past, present, and projected outcomes.

Looking to Figure 12, this illustrates fixed and floating offshore wind, offshore solar and wave sector average LCOE ranges along with current LCOE baselines marked for each technology. For each sector, the average LCOE values and the corresponding cumulative installed capacity for 2021, along with the most up to date learning rates were found through various publicly available reports**Error! Bookmark not defined.**[,38,41,4339]. By applying the learning rates to the respective sectors, LCOE pathways were calculated for each sector. CorPower Ocean and Oceans of Energy's expected LCOE milestones, along with a number of key points have also been plotted on the graph.

Fixed offshore wind LCOE values are currently between the higher end of 106 EUR per MWh to the lower end at 66 EUR per MWh, with the average LCOE baseline at approximately 86 EUR per MWh[3,4]. The global cumulative installed capacity for fixed offshore wind in 2021 was approximately 56GW[40]. The fixed offshore wind sector expected LCOE ranges were found using a learning rate of 8.3%[41]. Floating offshore wind LCOE is currently ranging between 194 to 124 EUR per MWh, with the average LCOE baseline at approximately 149 EUR per MWh[3,4]. The global cumulative installed capacity for floating offshore wind in 2021 was 123MW[42]. A learning rate of 9.5%[43] has been applied.

As previously mentioned, offshore solar is only a burgeoning sector with very little data to source in the public sphere, with only 0.3MW of global installed capacity[18]. However, the current LCOE baseline for offshore solar is estimated to be 354 EUR

[39] CSIRO, 2022. Wave energy generation and storage costs in Australia: an analysis for Wave Swell Energy Limited
[40] IRENA, 2022. Renewable Capacity Statistics, 2021.
[41] Pennock et al., 2022. Deriving Current Cost Requirements from Future Targets: Case Studies for Emerging Offshore Renewable Energy Technologies.
[42] DOE, 2022. Offshore Wind Market Report: 2022 Edition.
[43] ORE Catapult, 2021. Floating Offshore Wind: Cost Reduction Pathways to Subsidy Free.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

per MWh[44,45]. The learning rate used here is derived from the DNV 2022 report, at 17%**Error! Bookmark not defined.**. Finally, reports suggest the average wave LCOE range is between 260 to 600 EUR per MWh[35,37,38], with global cumulative installed capacity at approximately 24.7MW as of 2021[46]. Here, a current wave LCOE baseline of 269 EUR per MWh is shown, a learning rate of 17% has been applied[38]. This is summarised in Table 1.

In Figure 12, the vertical axis has a logarithmic scale with base 2 applied to it, therefore each grid line shows a halving of the costs as the installed capacity in MWs increases on the horizontal axis. The Horizontal scale is also logarithmic but in base 10 so that the wave, offshore solar and offshore wind can all be shown on the same axis for convenience. The horizontal black line in the middle of the graph shows the EU-SCORES LCOE target of 50 EUR per MWh. At different sections of the graph, each industry will reach this target LCOE without the help of the EU-SCORES project. However, the aim of EU-SCORES is to reduce the LCOE's with the implementation of cost-efficient offshore multi-source renewable energy parks. This will see the target LCOE being achieved at a quicker rate, along with other benefits such as efficient use of marine space, balanced energy systems and increased revenues.

---

[44] Bosh Solar, 06/01/2021, 'Offshore Floating Solar PV May Reach Maturity in 2030', https://www.bosch-solar.com/news/offshore-floating-solar-pv-may-reach-maturity-in-2030.html Date Accessed: 08/08/2022.

[45] Solar Edition, 04/01/2021, 'Offshore solar panels have the potential to reach the ground-mounted PVs in terms of LCOE', https://solaredition.com/offshore-solar-panels-have-the-potential-to-reach-the-ground-mounted-pvs-in-terms-of-lcoe/ Date Accessed: 08/08/2022.

[46] Ocean Energy Europe, 2022. Key Trends and Statistics, 2021.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

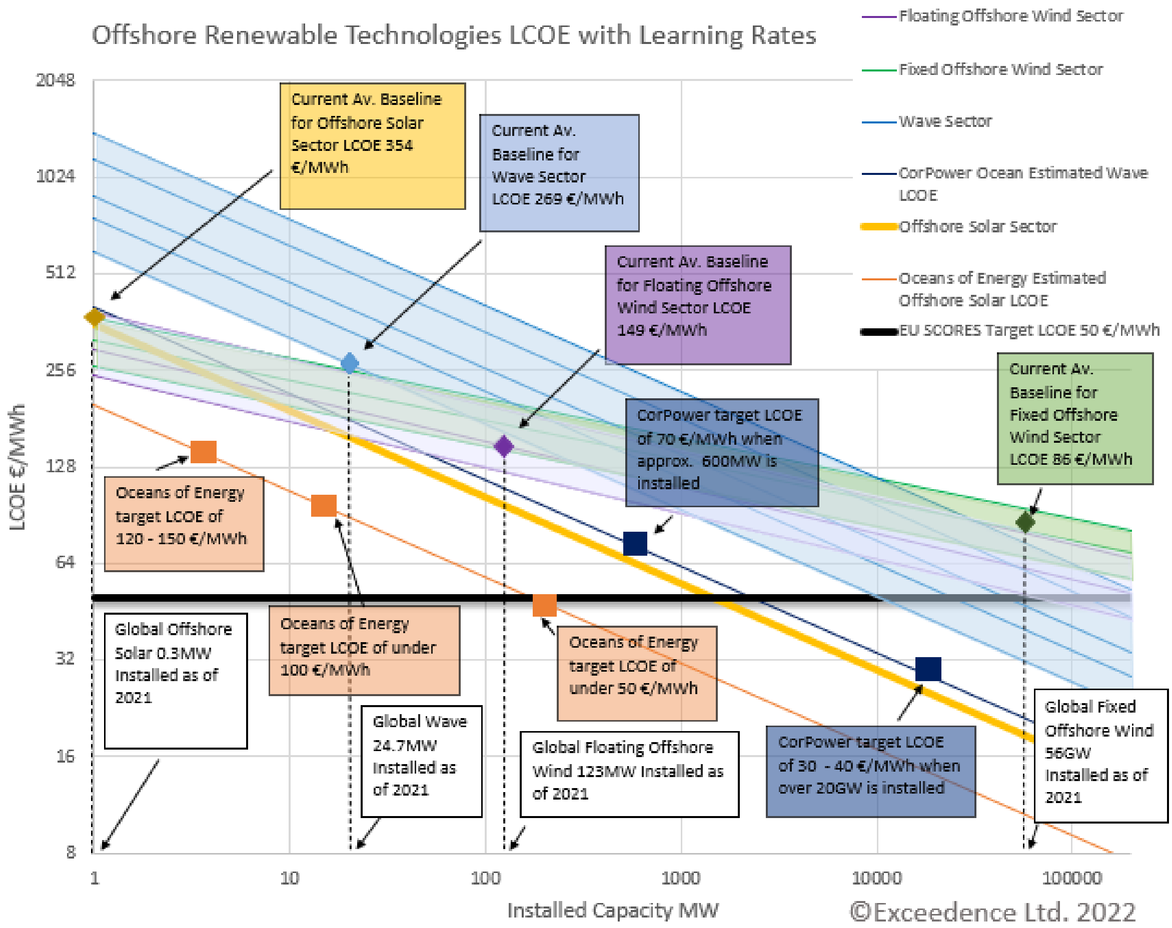


Figure 12: Sectoral LCOE Range for Offshore Technologies.

Table 1: Overview of data inputs and references from Figure 12.

Sector	Current Estimated LCOE (2021)	Learning Rates	Current Installed Capacity (2021)	References
Fixed Offshore Wind	66 – 106 EUR per MWh	8.3%	56GW	**DOE**, 2021. Offshore Wind Outlook Report. **ETIP**, 2021. Getting Fit for 55 and set for 2050. **GWEC**, 2022. Global Wind Report 2022. **Pennock et al.**, 2022. Deriving Current Cost Requirements from Future Targets: Case Studies for Emerging Offshore Renewable Energy Technologies.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

Floating Offshore Wind	124 – 194 EUR per MWh	9.5%	123MW	**DOE**, 2021. Offshore Wind Outlook Report. **DOE**, 2022. Offshore Wind Market Report. **DNV GL**, 2020. Floating Wind: The Power to Commercialize. **ETIP**, 2021. Getting Fit for 55 and set for 2050. **ORE Catapult**, 2021. Floating Offshore Wind: Cost Reduction Pathways to Subsidy Free.
Offshore Solar	354 EUR per MWh	17%	0.3MW	**Bosch Solar**, 06/01/2021, https://www.bosch-solar.com/news/offshore-floating-solar-pv-may-reach-maturity-in-2030.html **DNV**, 2022. The Future of Floating Solar: Drivers and Barriers to Growth. **Solar Edition**, 04/01/2021, https://solaredition.com/offshore-solar-panels-have-the-potential-to-reach-the-ground-mounted-pvs-in-terms-of-lcoe/
Wave	260 – 600 EUR per MWh	17%	24.7MW	**European Commission**, 2020. An EU Strategy to harness the potential of offshore renewable energy for a climate. **Ocean Energy Forum**, 2016. Ocean Energy Strategic Roadmap 2016, building ocean energy for Europe. **Ocean Energy Europe**, 2022. Ocean Energy Key Trends and Statistics 2021. **Ocean Energy Europe**, **ETIP Ocean**, 2021. 2030 Ocean Energy Vision.

Company	LCOE Targets		Learning Rates
Oceans of Energy	120 – 150 EUR per MWh	When 4MW of cumulative capacity is installed	17%
	< 100 EUR per MWh	Before 2025	
	< 50 EUR per MWh	By 2030	
CorPower Ocean	70 EUR per MWh	When 600MW of cumulative capacity is installed	17%
	30 - 40 EUR per MWh	When 20GW of cumulative	

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

		capacity is installed	

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

4. Hybrid Projects

As part of the EU-SCORES project, a number of business cases will be developed as part of a future deliverable due in 2025, one of which will look at full-scale hybrid energy parks. These types of parks are designed to combine two or more renewable energy technologies to produce energy in one location. Hybrid energy parks come with some potential risks but also an array of benefits. Source diversification should lead to an increase in energy reliability and subsequent low-cost energy systems will occur. Furthermore, with a continuous supply of electricity comes increased revenues.

Co-locating different technologies within a hybrid park should enable sharing part of the infrastructure needed, potentially including use of substation, marine vessels, cables as well as marine space, which may result in lower costs and a more efficient use of the marine space. The EU-SCORES project has a particular interest in co-location of offshore wind and offshore solar, offshore wind and wave, as well as offshore wind and offshore solar/ wave with integrated hydrogen production. The project will produce a number of business cases investigating several different of these scenarios in future deliverables.

As the wave, offshore wind (floating and fixed) and offshore solar industries progress from pre-commercial to commercial, sector learnings will occur. This will result in reduced industry/investment risk, as well as reductions in CAPEX and OPEX as supply chains establish, and as projects and turbines increase in size. Both the wave energy and offshore solar sectors stand to benefit from this rapid advancement of offshore wind development through the advantages of:

- supply chain economies of scale,
- installation and O&M experience and services,
- skilled labour and expertise,
- mooring and foundation technology,
- through sharing such as project co-development, co-location or combination projects,
- sharing of electrical infrastructure, of platform infrastructure, as well as
- through hybrid offshore wind/wave, offshore wind/offshore solar structures.

All of these, should impact on the overall LCOE of wave and offshore solar, driving the cost down more rapidly. Some challenges may present themselves at the inception of these offshore hybrid parks such as; the spatial planning needs to incorporate the operations and maintenance of the offshore wind turbines where maintenance vessels can manoeuvre around the varying devices. Cost reductions of technologies not yet mature may take longer as learning is ongoing. Risk assessment and insurability may add costs to the project.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.

5. Summary and Key Messages

This report presents the state-of-the-art for the offshore renewable energy sectors offshore wind (fixed and floating), offshore solar and wave for cumulative deployment and average LCOE ranges. A combined visual has been created to show the individual LCOE ranges along with the specific targets for the wave energy developers CorPower Ocean and the offshore solar developers Oceans of Energy, presented in Figure 12.

This figure shows the costs versus the cumulative deployment and allows the reader to see past performance, current status and future projections of costs. These costs have been presented as ranges derived from the latest reference data available given in Table 1. Furthermore, the baseline costs and projections of both companies deploying wave energy and offshore solar technology through the SCORES project have been overlayed along with the EU SCORES long term target cost.

The key outcomes from Figure 12 are:

- While fixed and floating offshore wind have lower average LCOE values at present, the graph shows offshore solar and wave on a cost reduction pathway that will make them competitive with other technologies.
- Both CorPower Ocean and Oceans of Energy have lower than their sector average costs based on their baseline and projected LCOE.
- Co-location reduces costs and improves the efficient use of marine space, via the enabling of shared infrastructure, shared use of substations, marine vessels, etc.
- Looking at the EU-SCORES LCOE target of 50 EUR per MWh it can be seen that both technologies are capable of reaching this independently, however co-location will see this target achieved sooner and with less cumulative deployment.

This project has received funding from the Europeans Union's Horizon 2020 research & innovation programme under grant agreement number 101036457.