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Costing and economic performance of the W2Power floating wind energy technology

Milestone 23 b

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DemoWind
Delivering cost reduction in offshore wind

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1. SUMMARY

This report describes a costing and performance analysis model and results used to assess the W2Power floating wind power solution economically, and documents the method and the inputs used to estimate the Levelised Cost of Energy (LCoE). The report is a contribution to Milestone 23 of the WIP10+ DemoWind project, which is focused on estimation of the overall rentability of investment, financing / funding opportunities and business models for W2Power. This report gives a set of validation results for three deepwater sites with a high-quality wind resource (as quantified in the companion report on Exploitable Areas) comparing results from initial stages of the project to the current improved model and W2Power system design. The results and the costing model are discussed in terms of their accuracy and sensitivity to key technical and economic parameters including the Weighted Average Cost of Capital, WACC.

2. INTRODUCTION

For deep-water wind power to be commercially viable, floating-specific solutions are needed with a focus on reducing cost. Supply chains must be developed and ready to capitalise on recent industry cost reductions in bid prices for bottom-fixed offshore wind developments. These dramatic cost reductions, starting in 2015 but known since the Borssele auctions in 2016, are ascribed mostly to structural and cyclical improvements as summarised by Fig. 1. The main cost reductions were achieved by the advance permitting of zones by applying maritime spatial planning (MSP), making environmental data available pre-permitting, and pre-arranged grid connections. Such legal reforms were strategic in de-risking the projects.

In terms of finance, availability of low-interest equity and debt, and competitive bids for larger wind farm size largely followed and were equally critical. Of a more cyclical nature, improved availability of vessels (custom and others available from oil & gas service at reduced rates) also contributed to reducing costs.

Such non-technological factors are expected to apply equally to deepwater/floating systems.

Countries offering deep-water areas for development will most likely adopt similar procedures. Floating wind must be ready for this by the early 2020s. Leading markets, *e.g.* France, will open first. (See companion report [1].)

	UK - 2014 First round CfD	NL - 2016 Borssele I and II	Indicative impact on LCOE
STRUCTURAL			
Strike prices [EUR/MWh, incl. grid conn.]	**170-188**	**87**	
Track record [TWh]	104	180	↘↘
Technical/operational innovation	ongoing	ongoing	↘↘
Bankable turbine suppliers [#]	2	5	↘↘
Turbine capacity [MW]	3-4	7-8	↘↘
Competitive bidding for subsidy	no	yes	↘↘
Pipeline and support certainty	no	yes	↘↘
Grid connection certainty	no	yes	↘
Wind farm capacity	90-400	700	↘
CYCLICAL			
Interest base rate [German bond 10 years]	-2%	-0%	↘↘↘
Steel price [EUR/t]	410-450	320-340	↘
Oil price [Brent, USD/bbl]	57-107	36-50	↘

Fig. 1. "Structural" and "cyclical" changes in cost drivers and their impact on LCoE from 2014 to mid 2016. Source: Roland Berger [2].

[1] Report from the same Demo Wind project, TTI-JEH-7060-WIP10+ M23a Exploitable Areas FINAL.

Floating wind systems have been demonstrated with 2- to 7-MW turbines, but remain rather cost-challenged in future markets where minimum power per foundation is likely to be 10MW:

Spar buoys are eminently stable and manufacturable but require very deep sites (estimated depths greater than c.150m at 10MW). They need very deep locations for up-ending the spar and assembling/installing the turbine. These may limit their accessible market potential. Even where excellent sites exist, as for the Hywind Scotland pilot array, transport and installation logistics will necessarily place high strain on costs.

Semi-submersible platforms designed to carry one single turbine, and so far demonstrated by WindFloat off Portugal and the two Fukushima semi's in Japan need to be scaled up and re-designed to take the greater height, weight and much higher loads of coming anticipated 10MW-class wind turbines. This results in very high masses of construction material needed, whether steel or (steel-reinforced) concrete is used. Thus, single-turbine semisubmersibles are severely cost-challenged.

Tension-leg based systems such as those presented by SBM for the Provence Grand Large pilot array realise only some of the benefits of floaters over bottom-fixed systems in that they continue to require extensive seabed work for preparing, installing and securing the base structure fastening the tendons, typically gravity-based. In this sense, wind TLP's can be viewed as an intermediate step from fixed to floating foundations, but not always are costs correctly presented.

Barge-type floaters such as those developed by Ideol should be considered not as semisub-mersibles but a particular category. Their hydrodynamic characteristics are less well proven than semisubs, with little experience from oil & gas, and few independent tests and verifiable tank-testing results have been published.

In contrast to all of the above, W2Power has since its inception been developed with a view to being commercialised. The use of a pair of 6 MW class turbines – proven and bankable – allows lower hub heights, less topsides weight and lighter aero-hydrodynamic loads from the turbines than what would be the case for a single turbine of 12 MW or higher rated power.

The use of a large, but light-weight, column stabilised floater draws on offshore oil-industry experience, back to semi-submersibles that did not need the deep draft heavy submerged pontoons. The latter evolved in 3rd and later-generation designs, as the industry moved into deeper, harsher waters, and needed ever heavier equipment.

Stability for W2Power is provided by spacing the columns widely apart to achieve the largest stabilising water-plane area and ingeniously designed heave compensation plates. W2Power uses platform yaw, eliminating error-prone yaw mechanisms and saving additional top head mass. Other advantages inherent in W2Power's design are the outward leaning towers that allow greater rotor diameters achieved at low cost by placing the hub outside the baseline of the platform geometry (Patented). This implies less construction steel need per MW, thus lower levelised Cost of Energy, LCoE, compared to essentially all competing approaches.

The result is a highly stable floater of lower hub height and better-distributed mass and loads than what can be achieved with equally rated single-turbine floaters. 5 to 6 MW turbines are commercial and bankable today and likely to drop further in their per MW cost).

But just how much lower costs? That is the purpose of the present study.

3. THE COSTING MODEL

The cost model used here is a development for the DemoWind project, building on extensive completed efforts with LCoE modelling. The model was first introduced in MARINA Platform [2] an EU FP7 funded project (2010 to 2014) conceived by 1-Tech, with coordinator Acciona and scientific lead NTNU.

MARINA Platform studied the potential economic benefits, and engineering and deployment challenges, of combining wind power (mostly, but not only, floaters in deep water) with other maritime resources. Modelling accounted for wind- and wave-induced loads and resources. More than 100 concepts for combining wind & wave energy were studied, with at least some preliminary cost analyses done for each as part of the screening and further assessment. For this reason, the core elements of the model used are quite robust having been applied to a great number as well as a great variety of offshore renewable energy (ORE) concepts.

As used in this DemoWind study, the cost- and performance model is a spreadsheet tool fully transparent to its user. Costs (CAPEX & OPEX) and performance are estimated for any size offshore energy developments, accounting for energy resources and cost elements related to construction, installation, operation & maintenance, and decommissioning.

All aspects of a development – down to details such as the numbers, day rates, sailing speed and distance of the tugboats used for installation – are accounted for. The model can handle smaller projects down to single demonstrators as well, because it was first calibrated on the Hywind Demo, whose developer Statoil was a full and active MARINA consortium partner.

As used by 1-Tech (since 2012), this configuration of the model is quite refined compared to the crude form used in MARINA. Notably, the tool features a redesigned user interface with all input and output parameters on two screens, which can also be printed pages, with most important data available at a glance. This encourages active use and “playing” with the tool and common parameters, which facilitates sensitivity studies and sometimes gives insight to improve planning and design, revealing trends not obviously expected.

For DemoWind, the model’s sophisticated wave-energy technology components have been “parked” (remaining instantly available) and the model thoroughly reviewed with a focus on refining and updating of the central cost elements, wind-turbine performance parameters and operational needs related to modelling the cost and performance of the W2Power platform. Accuracy and reliability are improved, while the model remains backwards-compatible.

All underlying data and assumptions are visible to the user and many have been re-worked with new, more current and accurate input. The model allows studying up to 40-year project duration and includes options for timed re-powering and (partial) re-development. However, as used here, a fixed 22-year project period is assumed in order to easily facilitate the direct comparison of different sites and wind-farm configurations. Installation is assumed to occur in the first year, followed by 20 years of commercial power production, and decommissioning in the last year. The functions for variable project timing remain in the spreadsheet and can be re-activated, but the effort required to get accurate quantitative comparisons is non-trivial.

[2] www.marina-platform.info

Data input and output is self-explanatory. On the “Main” screen, the wind resource is input as the annual mean speed and distribution parameter *k*. Wind data, including at sea, is available from the Global Wind Atlas (www.globalwindatlas.info), see Fig. 2, and many other sources.

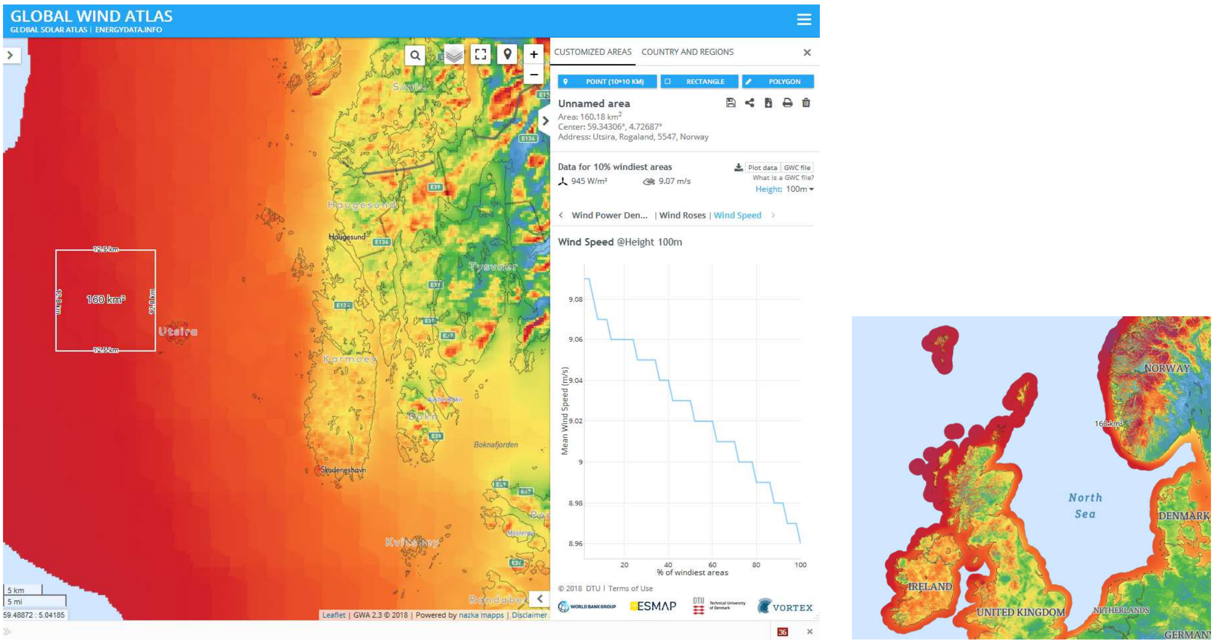

Fig. 2. Wind mean speed data for one test area studied. “Utsira II” is part of one of Norway’s proposed areas. The 160 km^2 marked could site one 640MW W2Power farm. The wind speed is read directly and it averages 9.03 m/s. If the entire 1010-km^2 area called “Utsira North” is developed using W2Power, it could yield more than 4 GW.

Wind data are normally measured with an anemometer and sorted in speed classes of 1 m/s. The Weibull distribution is a commonly used approximation for the wind speed distribution:

$$f(v) = \frac{k}{A}\left(\frac{v}{A}\right)^{k-1} \exp\left(-\left(\frac{v}{A}\right)^{k}\right)$$

The Weibull scale parameter A (m/s) is proportional to mean wind speed. The Weibull shape parameter k specifies the slope of the Weibull distribution and takes on a value of between 1 and 3. A low value for k signifies highly variable winds and constant winds are characterized by a larger k. A simplified graphic is shown on the “Main” screen.

The key financial parameter WACC (weighted average cost of capital) is chosen along with site data, platform design, turbine, materials and other choices. The output is visible without scrolling on a recommended monitor set-up (min. 1920x1080 pixel resolution, recommended 2560x1024, as in Annex 3, or 4k monitors). The worksheets allow inspecting and modifying all costs and specifications and the calculations are open for full user transparency. See Annex 1 for a full description of the model and Annex 2 for numerical parameters.

Wave-relevant parameters can also be input to the model, reflecting its history as a hybrid marine energy evaluation tool. When modelling wind-only cases, the wave parameters are helpful by indicating the wave loads on the platform though not necessary for obtaining the wind power performance or costs.

4. COST-MODELLING RESULTS

The use of the tool is illustrated by Fig. 3 below, showing the two "Main" screen segments. This case is for deeper-water areas near the formerly planned Argyll Array, NW Scotland.

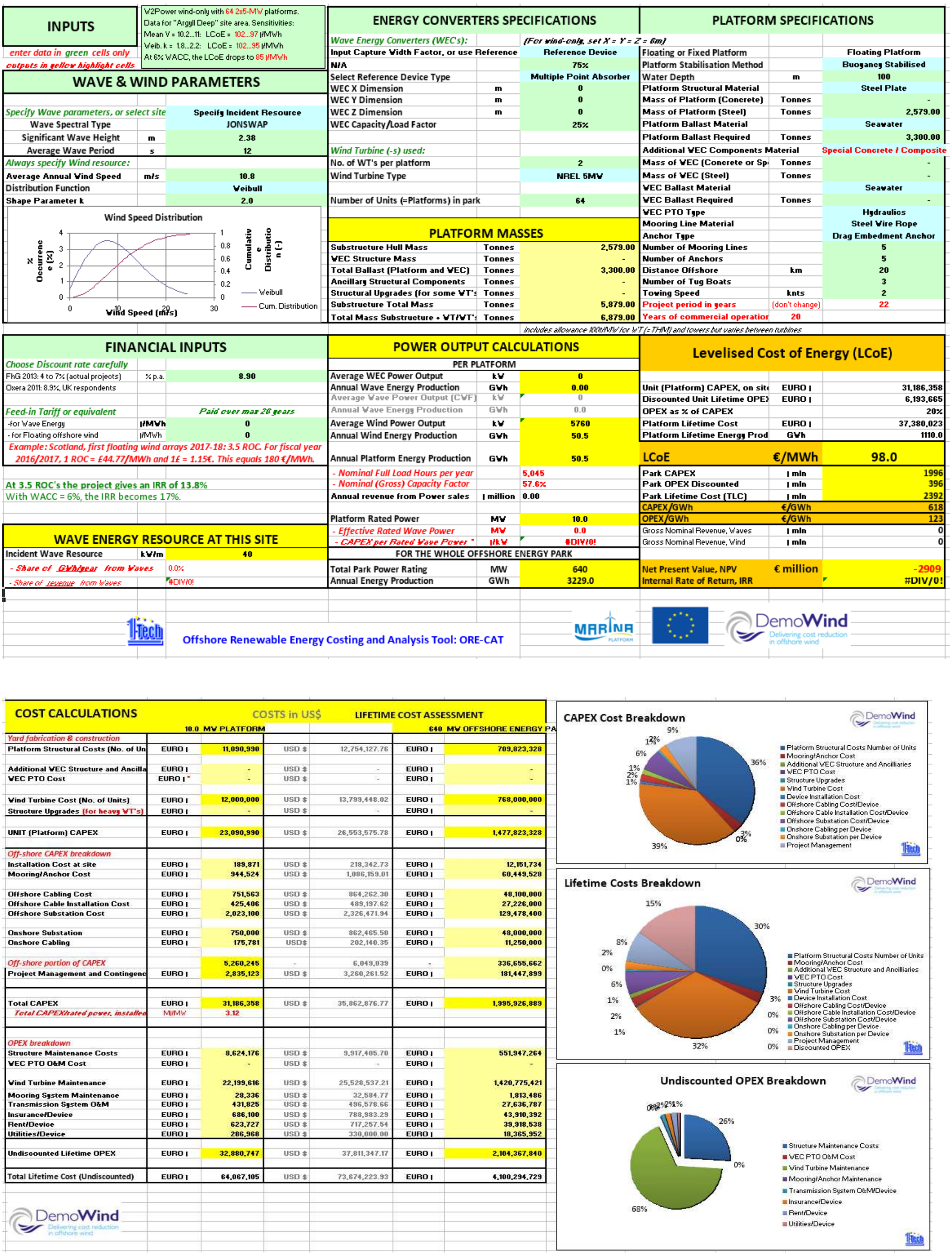

Fig. 3. Example cost and performance calculations for the case of "Argyll Deep", offshore Scotland. (Initial study).

This case concerns a potential 640-MW floating wind park development using, in the initial runs, 64 W2Power platforms each rated 10 MW. The output and graphics in the lower figure show all key costs for the entire park, and for each platform (or "unit"). Some comments:

The site, quite extensively studied by 1-Tech, is located in waters adjacent to the previously planned but cancelled 1800 MW "Argyll Array" bottom-fixed offshore wind farm [3], thus our moniker "Argyll Deep". 100 m water depth is assumed in order to not deviate too much from the published wind resource data (the plan for fixed foundations had a 50-m depth cut-off).

The best available wind and wave data have been used. In the "case description" box in the top left of Fig. 3 (upper) are listed sensitivities for the range of annual wind speed reported for the area and Weibull distribution k-factors (by simple curve-fit).

The platform design parameters, steel masses, moorings etc. correspond to the W2Power base case of design. The 2579-metric ton floater structure is assumed to cost €3,800 / tonne as fabricated, a cost equal to the actual quote by the fabricator chosen for the prototype built in the DemoWind project. Lower cost per steel is often quoted by developers: Statoil received several bids at 1500-1700 US$ / tonne for the steel spar structure when planning the Hywind Scotland pilot array [3]. Such a structure is simpler (with fewer welds and operations), so could be expected to be cheaper per tonne than a semisubmersible. However, also for a 4-column semi-sub proposed, a fabricated cost of €2,800 per tonne has been widely announced [4]. We therefore consider our assumed fabricated-steel cost for W2Power as highly conservative.

The wind-turbine purchasing cost assumed in the initial runs is €1.2m per MW, chosen to be in line with North Sea and other developments known in the years 2015-17. The wind-turbine performance data used in the initial runs are for the generic "NREL 5 MW" machine, used in many studies. Its good power curve and moderate top head mass were considered adequate for generic studies, but is far from an optimised choice for W2Power. While "turbine-agnostic" in its design, W2Power in planning commercial developments will of course need to optimise all choices for site conditions, control strategy, power performance, O&M and cost-efficiency.

Other parameter choices are also conservative. They are listed in Annex 1 and can be tested in the Excel tool (can be made available for non-commercial use, no warranties or support.)

The discounting rate, or WACC (Weighted Average Cost of Capital) in the initial base case is set to an extremely conservative 8.9%. Initial calculations were also done with WACC = 6%.

Note: All the modelling results in this study, and whose data are shown in Annex 3, are in the LCoE calculation mode, *i.e.* without assumed income from power sales, feed-in tariff or other support. Used in this mode, the output screen may display meaningless digits in the cells for NPV and IRR. While not intended as a full project financial tool, the model can also be used to estimate profitability (including taxes, depreciation and decommissioning) As an example, using FiT similar to the former UK ROCs for the above described initial case, at a 6% WACC, this gave interesting positive NPV from c.2 ROCs; at 2.5 ROCs, the predicted IRR was 8.4%.

[3] Statoil presentation at the "EERA Deep Sea Wind" conference, Trondheim, January 2015.

[4] M. Guyot (Eolink SAS), presentation at Offshore Wind Europe, London November 2018.

Cases modelled: (a) Initial study (2017) using generic data.

For the initial study, the W2Power platform deployed in 640-MW farms at three geographical areas representative of selected deepwater sites with a high-quality offshore wind resource:

- **Argyll Deep,** the Scotland area cited, a very high wind resource in the North-West Atlantic
- **Utsira II**, a high value North Sea deepwater area listed in Norway's former national plan as one of five suggested areas with the highest potential for future multi-GW developments [4].
- **Alboran Sea,** off peninsular Spain, representing a Mediterranean high-quality wind area.

In line with W2Power design philosophy ("design one – build many"), no attempt was made to strengthen or relax the platform design, using the same "scantling" (platform components) dataset for all three sites.

Wave data for the Norway site are measured and for the Spanish site, metocean data were collected by Enerocean in a previous project [5]. For the Scottish site, the wind & wave data were estimated based on available data for the general area including near the Limpet wave energy demo site, which is nearby (although more exposed to ocean swell).

The key modelling outcomes are shown in Table 1.

Table 1. Initial (2017) model results (LCoE in € / MWh) for 3 deepwater high-quality-wind areas. 640-MW project: 64 x 10MW W2Power platforms of identical design. 20-year commercial operation, Wind speed at 100 m. Costs include all CAPEX and OPEX.

Area (depth/distance to install. port)	Annual mean wind speed and k-factor	Significant wave height and period	Annual output of park	Nominal full load hours/yr	Gross capacity factor	**LCoE @WACC = 8.9%**	**LCoE @WACC = 6.0%**
Argyll Deep (100m/20km)	10.8 m/s k = 2.0	2.38 m 12 sec	3229 GWh	5045	57.6%	**98.0**	**85.1**
Utsira II (100m/20km)	9.03 m/s k = 1.88	2.18 m 12.3 sec	2618 GWh	4091	46.7%	**116**	**100**
Alboran Sea (100m/30km)	9.33 m/s k = 1.88	1.0 m 6 sec	2723 GWh	4255	48.6%	**113**	**98.0**

Note: The productive (equivalent full load) hours and capacity factor as modelled here do not include planned down time for scheduled O&M.

For the initial runs, total CAPEX for a 64-platform development, taking into account all costs including the on- and offshore cabling, substations, project costs, insurance etc. varied only very slightly at €2.0 billion (€1997m to €2018m) as a function of varying distance from shore.

CAPEX for the wind farms installed on site was €3.12 to €3.15m per MW. The unrealistically high discount rate of 8.9% (generally, few large projects would get built – in any sector – with so expensive capital) underestimates the OPEX over CAPEX, but the costing tool is showing un-discounted OPEX as well. The full input and output data are reproduced in Annex 3.

Cases modelled: (b) Updated study (2019) of commercial prospects post-2022.

For the final updated issue of this study, the same sites were modelled at conditions relevant to future possible commercial tenders (500+ MW scale) in the years following two announced French bidding rounds in 2021/22 (of 250MW at €120 and €110/MWh [5]). See our companion report on Exploitable areas [1]. The following modifications to the "Initial" study were applied:

1. A pair of **6-MW** rated turbines was applied instead of the generic 5-MW's used in the initial runs, thus realising the W2Power platform's target design power of 12 MW. This "P130-6.0" turbine has its partly-optimised power curve, blade characteristics and top head mass taken from from confidential data by EU and non-EU turbine developers.
2. CAPEX per MW for these turbines was set at **€1.0m/MW** (instead of €1.2m). Recent reports tell of 5- to 6-MW turbine sales for offshore at less than this price already [6].
3. Discount rate ("WACC") was assumed at **5.5%,** based on a study by BVG Associates for Wind Europe of post-2025 offshore development scenarios in European seas [6].
4. Wind turbine maintenance cost was set at **€100/kW/year** *(vs.*150 in the initial cases). €100 is mid-range of a data set published in 2016 [7] and anticipates falling O&M cost of mature turbines. For comparison, DONG reported c.€90/kW/year as a mean total OPEX for all of its existing fixed-foundation wind farms cumulative before 2015 [7].
5. Hull maintenance for the platform at **3%** of CAPEX per year (instead of 4%) taking into account experience with protection against fatigue, corrosion etc. anticipated.

With these parameters, and all others as in the initial runs, following results were obtained:

Table 2. Updated (2019) model results (LCoE in € / MWh) for 3 deep-water high-quality wind areas, post-2022 commercial scenario. 648-MW project: 54 x 12MW W2Power platforms, 20-year commercial operation, wind speed at 100m. Costs include all CAPEX and OPEX.

Area (depth/distance to install. port)	Annual mean wind speed and k-factor	Significant wave height and period	Annual output of park	Nominal full load hours/yr	Gross capacity factor	**LCoE @WACC =5.5%**	LCoE @WACC =4.0%
Argyll Deep (100m / 20km)	10.8 m/s k = 2.0	2.38 m 12 sec	3232 GWh	4987	56.9%	**64.2**	59.1
Utsira II (220m / 20km)	9.03 m/s k = 1.88	2.18 m 12.3 sec	2613 GWh	4032	46.0%	**78.5**	72.1
Alboran Sea (100m / 30km)	9.33 m/s k = 1.88	1.0 m 6 sec	2719 GWh	4196	47.9%	**76.0**	69.9

The cost for a 648-MW W2Power development at 3 sites studied is seen to be in the same range as those for ongoing conventional developments at Borssele I & II, a 752-MW project awarded to DONG in 2016 with commissioning scheduled 2020. (See discussion in Sec. 6).

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[5] *Stratégie française pour l'énergie et le climat: programmation pluriannuelle de l'énergie: Synthèse,* Ministère de la transition écologique et solidaire (French Ministry responsible for environment and energy), published 25-01-2019.

[6] *Unleashing Europe's offshore wind potential:* A study by BVG Associates for Wind Europe published June 2017.

[7] *Global cost analysis – the year offshore wind costs fell,* Wind Power Monthly 29-01-2016.

Total CAPEX is now €1.72 - 1.78 billion, or c. €2.7m per MW. It is clear from the results that cost-efficient, large floating wind farms are within reach as the W2Power solution is matured. A 4% WACC for floating is optimistic today but less so post-2022. It will enable W2Power at <60€/MWh without assuming further platform design improvements or turbine developments.

Mooring & Anchoring Costs

In this DemoWind project, a separate TTI engineering study was carried out dedicated to the mooring system [8]. The work is applicable to the full-size W2Power solution for sites similar to the "Utsira II" modelled in the present work.

The costing tool used in the present report for windfarm-scale calculations does include an approximate estimation for conventional catenary mooring systems with drag embedment or suction anchors (see details in Annex 2). However, the dedicated mooring engineering study adopted a sophisticated design tool (a time domain, hydrodynamic-mooring coupled model accounting for wind turbine loads) to estimate more accurately CAPEX for various mooring-system configurations developed for DemoWind. Table 2 summarises the full-scale cases:

Table 2. Mooring costs for Utsira II case study, from TTI engineering study report [8]

Mooring system type	Mooring cost share of total CAPEX for single unit (not including mooring installation costs)
Steel Chain catenary system	16%
Nylon-Chain, Semi-taut legs*	11%
Nylon, Taut leg*	2%

*Note : * mooring systems not offered as estimation choices by LCoE model as used in the present study.*

The above estimates compare to the LCoE modelling in the present report (Annex 3 g, h), in which it was estimated that, for a steel chain/wire catenary, the share of the mooring costs to total CAPEX for a single unit would be 4% (not including installation costs).

Key points to note from the two analyses done in this DemoWind project are that:

- The LCoE model for the Utsira case tends to underestimate mooring CAPEX costs for steel-based moorings,
- Mooring cost estimated using the LCoE model seems more representative of Nylon based moorings (termed "Synthetic Rope" in the model, which doesn't distinguish between the various polymers used in mooring lines nowadays).

It would be impractical to develop this Excel-based tool to accurately estimate mooring costs. Rather, the results highlight the importance of assessing mooring costs using a time-domain dynamic model on a case by case basis (to inform LCoE estimations).

It is also noted that for the 1:6 scale prototype built and deployed at sea, a Nylon-Chain semi taut mooring was adopted as being the most practical for this first-of-a-kind deployment.

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[8] X. Wadbled, *WIP10+ Full Scale Mooring Design, Milestone 15 (II)* Report TTI-XW-2018-7060-R012.

Application to Demo and Pilot Array installations

The costing tool has been used in the DemoWind work only for W2Power. However, since all input parameters are open and fully flexible, other design can quickly be assessed if their key data are available. This is useful for quickly scanning the competitive position. Quoting one example, W2Power was not surprised that another developer in 2017 found it impossible to complete a 10MW pilot project. [widely reported, *e.g.* RENews 20.07.2017].

Assuming wind / wave conditions at the Dounreay Tri test site as at Argyll Deep, a W2Power demonstrator at this site (<15 km offshore) would reach an LCoE of 152 €/MWh. (For single demonstrators, the cabling costs are excessive; however, already for a 3-platform (30MW) array a more realistic 111 €/MWh is predicted, only 13% higher than a full-size development). For a single demonstrator, with the 3.5 ROC at the time assumed for this project, our model yielded a positive NPV of €13m on a €52m CAPEX demo. (For a 3-platform W2Power pilot array, corresponding numbers are NPV €96m on a €109-m budget, with an IRR of 10.3%.)

The competing design uses a much larger, heavier platform needing 6,000 tonnes of steel. We do not know their steel cost, reports at the time were of construction in Singapore and Korea, not famous for low-cost fabrication. Assuming the same steel cost as for W2Power, the competitor's LCoE works out at at least 200 €/MWh. So, it is not surprising that they struggled to get the finances together: Our model yields a negative NPV of -€9m on what would for them be at least a €69m CAPEX demo.

6. CONCLUSIONS AND DISCUSSION

The cost-modelling results in this study shows that W2Power is well positioned to realise cost reductions that may open for commercial introduction of floating wind power soon after 2022. All key factors for this are in the model, and they can be estimated with reasonable accuracy.

The range of LCoE estimated for W2Power at the three sites studied in a post-2022 scenario (64 – 79 € per MWh) is shown by the bright green arrows on Fig. 4. The figure compares this estimate to cost of other renewables and recent developments in bottom-fixed offshore wind.

LCoE for W2Power is here lower than the (stated) cost range for biomass electricity and also mostly lower than solar PV, though still higher than for onshore wind. Notably, the estimated LCoE of W2Power can be seen to approach the award prices for Dutch bottom-fixed offshore projects Borssele III and IV, won by a Shell-led consortium in late 2016, and for Kriegers Flak in Denmark, won by Vattenfall. In the figure (made by consultancy Roland Berger), the value 87 €/MWh is highlighted in particular: This was the bid awarded DONG (today Ørsted) in the preceding Borssele I and II auctions, including grid-connection costs at the time estimated to be €14/MWh. This was considered "the major cost breakthrough" as explained in Section 2.

The findings in the present study show that W2Power – always intended as the most cost-efficient floating solution – could achieve an LCoE approaching the low bids on more mature bottom-fixed projects. While many claims have been made about future cost reductions, to our knowledge no other floating concept has documented such results in a comprehensive cost-modelling exercise using a transparent methodology, inputs and parameters.

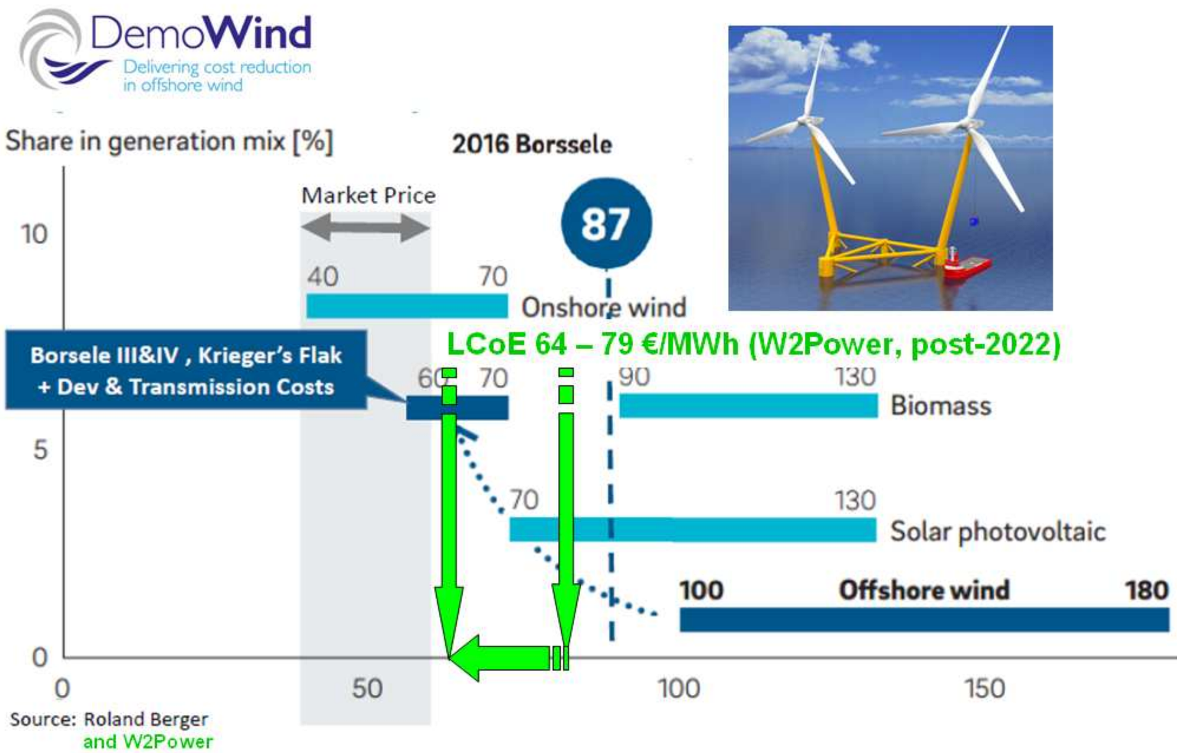

Fig. 4. Economic performance for W2Power in post-2022 developments *vs.* reference data as quoted by Roland Berger consultancy [2] for Borssele field (fixed foundations, commissioning in 2020). Notes: the 87 €/MWh quote for Borssele includes grid connection at 14 €/MWh and W2Power cost includes grid connection as estimated by the tool used in this study. Discount rates used are 5.5% to 6.5%. Full details in Tables 1 & 2 and Annex 3.

But how robust is this comparison?

Clearly, seeking to establish a baseline for comparing future W2Power cost estimates, two essential parameters are wind resource and the weighted average cost of capital (WACC). Average mean wind speeds at Borssele, quoted as 9.6 m/s at a central point [9], are higher than the Utsira and Alboran sites, though significantly lower than at the Scottish site. Several more sites could be added in further study, extending geographic and wind speed range.

Next, obviously, comparing LCoE estimations for a novel, pre-bankable, floating solution at a TRL = 6 to strike prices at auction for “safe” projects in well-explored areas is quite a stretch. When bidders decide their price, LCoE is usually not disclosed, and the actual cost of capital to obtain commercial value for the company is a closely guarded secret. G. Hundleby of BVG commented at the time of the first Borssele auction [10] that another estimate for the Borssele I-II LCoE could be made using “only the advantages of site conditions and the government’s approach to transmission and development costs”. This would be €84/MWh, which in the UK (at 8.5% WACC) “would have implied corresponding SDE+/CFD bids at €92/MWh”.

In 2018, analysing market prospects for Ørsted, financiers Credit Suisse considered [11] that “the competitive auction IRR’s were close to the WACC” and estimated “LCoE for projects sanctioned 2018 to be online in 2022” was €66/MWh, or €54/MWh without grid connection. Credit Suisse quoted a value for WACC of 6% at the time for 500MW projects with 9.5MW turbines on monopiles, 30km from shore and in 34m water depth. However, Energinet of Denmark [7] in analysing various bids with Final Investment Decision (FID) between 2015 and 2020 – including both Borssele I/II and III/IV auctions and others – reports that interest rates used as the basis for the Borssele III/IV and Kriegers Flak bids must have been quite significantly lower than for Borssele I/II (without giving a numerical value).

It is well known that WACC varies between countries depending on the characteristics of their financial markets – even for more mature technologies than offshore wind. A good illustrative example from Germany’s *Agora Energiewende* [8] is shown in Fig. 5. In 2014, on-shore wind projects enjoyed a WACC of around 4% in Germany, whereas values lower than the UK WACC of 6.5% were also reported in Belgium, France, the Netherlands and Denmark. In Austria and Finland, WACC levels were comparable to the UK, while countries such as Portugal, Italy and Sweden had to plan projects at a significantly higher WACC, up to 9%.

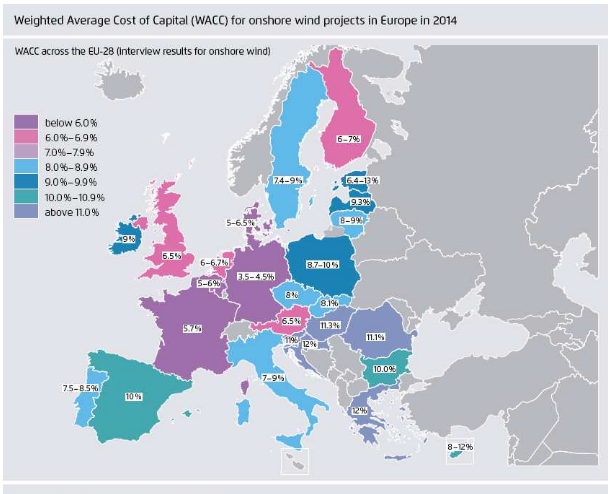

Fig. 5. WACC for European onshore wind projects 2014 [9].

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[9] Wind Farm Zone Borssele Wind Resource Assessment, Ecofys report to RVO, certified by DnV-GL, issue 4 of 17.09.2015.

[10] G. Hundleby, ”Dong’s Borssele Costs”, Blog post BVG Ass., 29.07.2016, https://bvgassociates.com/dongs-borssele-costs/

[11] M. Freshney et al. Equity Research Eledtric Utilities, 28 February 2018, https://rave.credit-suisse.com/disclosures/view/

Specifically for offshore wind, a study by IEA Task 26 [9] compared levels of LCoE between countries for (fixed-foundation) offshore wind projects in a report published in Oct. 2018. The analysis, taking as a basis offshore windfarms commissioned in 2017/18 (using estimates for countries in which none were), accounted for numerous other country differences, *e.g.,* wind resource, sea depth and distance from shore and grid-connection point with a “representative case” in each country. The IEA Wind experts considered debt : equity ratios from 55 : 45 (for the US) to 75% debt (Germany, Belgium) and assumed % p.a. costs of equity and debt, the latter varying from 6.8% in the US to 3.0% in Japan. Accounting for inflation (through wrongly for Japan), the study obtained a set of pre-tax “real WACC” values shown in Figure 6 below:

Financial Inputs		2017 Baseline	Netherlands	UK	Belgium	Denmark	USA	Germany	Japan
Debt/equity ratio	%	70.0%	70.0%	70.0%	75.0%	70.0%	55.0%	75.0%	70.0%
Cost of equity	%	15.0%	13.0%	12.5%	13.0%	12.8%	12.1%	12.0%	15.0%
Cost of debt	%	5.0%	4.0%	4.0%	5.0%	4.8%	6.8%	4.0%	3.0%
WACC (pretax nominal)	%	7.1%	6.70%	6.55%	7.00%	7.15%	9.16%	6.00%	5.98%
Annual inflation	%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%
WACC (pretax real)	%	4.67%	4.81%	4.67%	5.11%	5.26%	7.23%	4.13%	2.65%

Fig. 6. Financial parameters from IEA Wind study of offshore LCoE, its Table 13, Oct. 2018 [9].

On the basis of this previous work, it appears that cost and comparisons of the present study are quite robust with regard to baselines and financial parameters assumed. The assumption of 5.5% WACC for W2 Power does not seem poorly justified compared to the studies by IEA Wind, Agora Energiewende and Energinet. In a 2022 perspective, such a value seems quite reasonable in a situation with “real” WACC in the 4.1% to 5.2% range quoted for established technologies in proven, well-described areas – and with reference to 2017/18. This becomes quite natural in view of the high market attention and widely assumed maturation of floating offshore wind, including technologies promoted by huge players like Equinor, Naval or Aker. Even the 4% WACC “currently optimistic” assumption could be taken as a guide to future prospects in high-growth floating wind scenarios. Countries like Japan, with huge resource, high power costs and few alternatives may be seen as early entrants – obviously only if their technical, regulatory and other barriers to offshore wind (not just floating) can be addressed – this due to the size and overall characteristics of their capital markets.

In the UK, deepwater sites in West of Scotland are commercial prospects for W2Power with their excellent resource and suitability for our robust platform (designed for high wave loads). Also, sites in the North Sea off Norway, and in the Mediterranean, would be commercially attractive post-2022, given further optimisation of, *e.g.,* platform and turbine sub-systems.

Amongst refinements to be added tp the model, more accurate wind turbine data, detailed site parameters and a wider range of depth, installation procedures and O&M conditions are important. A key feature of W2Power is the multi-use potential of the platform, greater than for other floating wind systems due to its large physical extent. This provides ample space for additional revenue streams that could improve further its economic performance. Examples include on-board energy storage, use as a floating substation (while on full production), sea-water desalination, and fish farming. A generalised framework for estimating costs & benefits of additional uses was developed by 1-Tech in the MARINA Project and published [10]. The economics model can with a manageable effort be expanded to handle all these upsides.

7. REFERENCES

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[9]. Noonan et al., *IEA Wind TCP Task 26 Offshore Wind International comparative analysis,* International Energy Agency Wind Technology Collaboration Programme, Oct. 2018, NREL.

[10]. J.E. Hanssen, P. Mayorga and L. Margheritini, *Proposed methodology for assessing cost of synergies between Offshore Renewable Energy and Other Sea Uses,* presented at the 11th European Wave & Tidal Energy Conference, EWTEC, Nantes (France) 2015.

Annex 1: Detail description of the costing model

Background

The objective of the economics tool is to estimate the power output of a floating offshore renewable energy platform, estimations for CAPEX and OPEX, to generate an estimated cost of electricity (CoE). The costing parameters were taken from literature, correspondence with relevant suppliers and technical studies primarily by NTNU and Acciona on offshore structures within the MARINA Platform FP7 project.

Updated numbers are added for many of the parameters, compiled from recent literature in the post MARINA period 2014-19. These are visible to the user, in most cases including a comments, and can be set. Most of them are on the tab *"Costs & General Specifications"*.

Inputs

All user input is in green highlighted cells, outputs appear in yellow or gold-highlighted cells.

Resources and Financial inputs

Wind resource is specified as average annual wind speed in m/s and Weibull distribution k-factor. Wave parameters are specified by wave spectral type (JONSWAP or Bretschneider), significant wave height (meters) and average wave period (seconds). A few predefined sites are available to choose.

The financial functions in the tool mostly being hard-coded to limit unrealistic predictions, the only financial input normally set by the user is the Discounting rate, approximately equal to the "weighted average cost of capital" (WACC). For estimations of NPV and IRR, a separate feed-in tariff can be set for wind- and wave generated electricity (if calculated over the entire project period). The costing tool also allows other annualised incomes as well as certain non-annual recurrent incomes, and anticipated power price scenarios can be added for handling "subsidy-free" offshore developments. However, the tool is limited in its capability to handle more complex conditional support mechanisms such as "Contracts for Difference" (CfD).

Platform Specifications

The platform structure, wind-turbine data, and wave-energy converter structure may be input as a full set of parameters for defined concepts or separately to assess concepts with distinct component and/or materials choices possible. Platforms modelled may be buoyancy, ballast- or mooring-line stabilised, corresponding roughly to semi-submersibles, spars and TLP's.

A choice of platform materials can be selected, independently of the platform type:

- Steel Plate (thickness can be set, default is 30 mm)
- Mass Concrete *(i.e.,* without reinforcement bars, "rebars")
- Reinforced Concrete *(i.e.,* with stainless steel reinforcing bars)
- Special materials, such as concrete epoxy-coated rebars, or composites

A choice of ballasting material and ballasting mass is available so that a given total displacement of the floating structure can be accurately represented.

Energy Converters Specifications

Wind Turbine Inputs

Wind turbines are modelled as a sub-system, *i.e.* the rotor blades, hub and nacelle housing the power train. Cost in €m/MW is set on the "Costs & General Specs" tab. For conventional rolled-steel towers, tower mass is added to the mass of platform steel, with correction factors accounting for heavier turbines with nacelle top head mass (THM) >300 or >360 tonnes.

The number of turbines per platform is selected. A drop-down menu selects from WT models whose validated power curves are known. New turbines are added on the *WT Data Floating* tab. In this work, two new turbines were added and a third updated, thus extending the range of the costing tool to handling W2Power units with a total wind power rating of 12 MW.

Originally, the model allowed wind-turbine costing for mass purchase by a reduction function with a factorial reduction of up to 50% from the 101st turbine. This is less meaningful today as turbine cost for large wind farms is usually negotiated, so WT cost is fixed at the input value, although a trace remains in the tool's labeling of turbine/platform cost by "Number of Units".

Wave Energy Converters (WEC's) Inputs [Not used in this project].

The performance of WECs on hybrid (wind & wave) platforms can be calculated by two methods, (1.) for a specific device if validated tank-testing data are available, or (2.) by using power matrices from reference devices which are scaled to the appropriate size according to a scaling factor method developed in the MARINA Platform project. For the latter case, the surface area of the device and the size of any component is taken from relevant *SolidWorks* drawings. A separate WEC capacity factor is also available.

WEC Power Take Off Inputs [Not used in this project].

The Power take-off (PTO) technology used for the (optional) WEC is specified under the "Platform specifications". A choice of PTO types, ballast material and ballast mass for the PTO is available. The PTO input can be chosen by either of four technology options: Air ("Wells") turbines, Hydraulics, Water Turbines, or Direct Drive PTO.

Mooring and Anchor System Inputs

The model does a basic calculation of mooring loads based on the acceleration of maximum wave height and platform mass (with ballast), including a factor of safety. Inputs from studies in MARINA provided data for mooring line lengths at given water depth. Buoyancy-stabilised platforms (i.e. semisubmersibles) are modelled with catenary moorings and three different line materials may be selected: "Steel Chain", "Wire Rope" and "Synthetic Rope". Each material has a different cost per metre per tonne of breaking force. The mooring lines are coupled with suitable anchors. Each anchor's requirements is based on the mooring load.

Platform Installation Inputs

The installation of floating platforms is assumed to be done using tug boats. A ratio of days per km from shore is utilised in the economics tool, multiplied by the tug and labour day-rates and the distance offshore of the installation (assumed to be equal to the distance from port).

Offshore and Onshore Cabling Inputs

[These are not normally chosen as inputs, but can be accessed by an expert user]. All cables are assumed to be AC and trenched when installed. 33kV cable is used to connect platforms at sea and 150kV cabling connects the onshore and offshore substation, if included. Spacing between platforms is assumed based on feedback from technical studies in MARINA. A test feature added in the course of this work allows modelling “pilot arrays” or small farms in the range of tens of MW at up to 15 km from shore using a fairly sophisticated cost interpolation procedure. This does not assume an offshore substation. In any case, the model assumes that an offshore substation is required if the power rating of the farm exceeds 100 MW.

Maintenance Costs

Maintenance costs in the base case is taken as a fraction of the relevant component cost and is calculated separately for the hull (floater structure), the wind turbines, the moorings, cable and substation connections, and other equipment (e.g. wave-energy conversion). For the present project a modification was added allowing comparison of wind-turbine O&M by the MWh produced and MW installed.

Other Operational Cost Inputs

Other OPEX costs included in the model are Insurance of the installation, taken to be 3% of CAPEX, Rent of devices, taken as 2.5% of CAPEX, and Utilities cost, which is estimated at €3,500 per MW capacity per year. All these parameters can be readily changed or updated.

Outputs

Following the specification of the platform components, CAPEX and OPEX for the lifetime of one device in the farm is calculated and output. It is displayed in a costs breakdown table as shown on the right-hand monitor on the Main screen. Costs subtotals are split into the cost of the device, the total CAPEX and the Undiscounted OPEX.

Total Lifetime Cost (TLC) is calculated by adding CAPEX and the Discounted lifetime OPEX. The Levelised Cost of Energy (LCoE) is calculated by dividing the total annualised costs by the annual energy output of the platform. This calculation uses a “Capital Recovery Factor” (CRF) as in conventional annuity calculations and calculated as a function of WACC.

The tool includes a tab for the input of renewable energy feed-in-tariff (FIT) and can also be modified for other fixed-term revenue support. If revenue is set to zero, the model estimates the LCoE. If the FiT is set as input, or expected market prices of electricity added (manually) added to the appropriate tab, the model will yield Net Present Value (NPV) and Internal Rate of Return (IRR) for the project modelled. These financial indicators are useful for comparison of options, but the model is not intended as a quantitative commercial project-modelling tool.

Further performance indicators such as the nominal full-load hours per year,Capacity factor, CAPEX per rated power and, for wave-energy-enabled cases, % share of wave power, are also provided in the “Main” screen outputs. The model is particularly useful by giving the user rapid, quantitative data for the impact of changing a wide range of cost factors, alone or in combination, all data appearing at a glance easily compiled for detailed sensitivity analyses.

Annex 2: Costs & General Specs for initial cases modelled

(see text for descriptions of specs modified for the uodate runs).

COSTS TABLE

				EURO€	
Concrete + Placement				437.00	€/tonne
Mass Concrete				437.00	€/tonne
Marine Grade Steel + Structure Fabrication				3,800.00	€/tonne
Marine Grade Steel + WEC Fabrication				3,800.00	€/tonne
Stainless Steel Rebar				2,100.00	€/tonne
Epoxy Coated Rebar				805.00	€/tonne
Cathodic Protection	where this comes from? looks high!			500.50	€/tonne of Steel
Concrete Ballast				145.00	€/tonne
Sand Ballast	take "sand" in a broad sense :-)			87.50	€/tonne
Ancillary Structural Components				0%	Hull Cost
Hydraulic PTO				800.10	€/kW
Water PTO				800.10	€/kW
Air PTO				800.10	€/kW
Direct Drive PTO				800.10	€/kW
Typical PTO System Efficiency				50%	
Discount Rate Factor				1.00	
Mooring Chain Factor				0.23	€/tonne force/m
Mooring Synthetic Rope Factor				0.26	€/tonne force/m
Mooring Steel Wire Factor				0.21	€/tonne force/m
Drag Embedment Anchor			25	35,000.00	€
Suction Pile Anchor			15	17,500.00	€
AC Cable 33kV				400,000.00	€/km
AC Cable 150kV				750,000.00	€/km
Offshore Substation				200,000.00	€/MW
Onshore Substation				75,000.00	€/MW
Hull Maintenance Steel				4%	Hull Cost
Hull Maintenance Concrete				0.4%	Hull Cost
PTO Maintenance				20.00	€/MWh
Mooring System Maintenance				3%	Mooring/Anchor C
Wind Turbine Purchase Cost				1,200.00	€/kW (1 Device)
Wind Turbine Maintenance				20.00	
Structural Upgrades				0%	WT Cost
Onshore Cabling 33kV				400,000.00	€/km
Onshore Cabling 150kV				750,000.00	€/km
Onshore Cabling Distance				15	km
Platform Installation					
	Tug			30,000.00	€/day
	Labour			8,500.00	€/day
	Mileage			140.00	€/km
	Cable				
		Trenched		282,000.00	€/km
		Un-trenched		100,000.00	€/km
		Rock Armoured		1,000,000.00	€/km
	Anchor				
		Drag Embedment		10,500.00	€/anchor
		Suction Pile		12,600.00	€/anchor
Transmission System Maintenance					
	Offshore Substation			0.4%	Cable CAPEX
	Cables			200,000.00	€/annum
Seabed Preparation per Foundation				107,500.00	€/unit
	Geophysical Survey			7,500.00	€/unit
	Bore Holes			75,000.00	€/unit
	Cone Penetration Test			75,000.00	€/unit
Dredger/Filler Ship				3,750.00	€/hour
Wind Turbine Installation Ship				250,000.00	€/day
Foundation Installation Ship				150,000.00	€/day
Backfilling Barge				1,500.00	€/hour
Cable Laying Ship				100,000.00	€/day
Container Ship				30,000.00	€/day
Piling				1,100.00	€/tonne weight pla
Insurance				0.1%	
Rent				2.0%	
Project Management and Contingencies				10%	of CAPEX
Utilities				1,500.00	€/MW
Decommissioning				25%	CapEx

General Specifications

Steel Plate Thickness	0.03	m
Concrete Wall Thickness	0.3	m
Concrete Density	2.4	tonnes/cu.m
Steel Density	7	tonnes/cu.m

Annex 3: Inputs and Outputs for the cases modelled

a) Argyll Deep site, initial (2017) calculation, “Main” screen 1

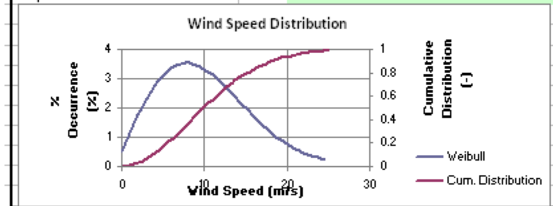
INPUTS

enter data in green cells only
outputs in yellow highlight cells

W2Power wind-only with 64 2x5-MW platforms.
Data for "Argyll Deep" site area. Sensitivities:
Mean V = 10.2...11: LCoE = 102...97 €/MWh
Weib. k = 1.8...2.2: LCoE = 102...95 €/MWh
At 6% WACC, the LCoE drops to 85 €/MWh

WAVE & WIND PARAMETERS

Specify Wave parameters, or select site:		Specify Incident Resource
Wave Spectral Type		JONSWAP
Significant Wave Height	m	2.38
Average Wave Period	s	12
Always specify Wind resource:		
Average Annual Wind Speed	m/s	10.8
Distribution Function		Weibull
Shape Parameter k		2.0



ENERGY CONVERTERS SPECIFICATIONS

Wave Energy Converters (WEC's):		*(For wind-only, set X = Y = Z = 0m)*
Input Capture Width Factor, or use Reference Device		Reference Device
N/A		75%
Select Reference Device Type		Multiple Point Absorber
WEC X Dimension	m	0
WEC Y Dimension	m	0
WEC Z Dimension	m	0
WEC Capacity/Load Factor		25%
Wind Turbine (-s) used:		
No. of WT's per platform		2
Wind Turbine Type		NREL 5MW
Number of Units (=Platforms) in park		64

PLATFORM MASSES

Substructure Hull Mass	Tonnes	2,579.00
WEC Structure Mass	Tonnes	-
Total Ballast (Platform and WEC)	Tonnes	3,300.00
Ancillary Structural Components	Tonnes	-
Structural Upgrades (for some WT's)	Tonnes	-
Substructure Total Mass	Tonnes	5,879.00
Total Mass Substructure + WT/WT's	Tonnes	6,879.00

includes allowance 100t/MW for WT (=THM) and towers but varies between turbines

PLATFORM SPECIFICATIONS

Floating or Fixed Platform		Floating Platform
Platform Stabilisation Method		Buoyancy Stabilised
Water Depth	m	100
Platform Structural Material		Steel Plate
Mass of Platform (Concrete)	Tonnes	-
Mass of Platform (Steel)	Tonnes	2,579.00
Platform Ballast Material		Seawater
Platform Ballast Required	Tonnes	3,300.00
Additional WEC Components Material		Special Concrete / Composite
Mass of WEC (Concrete or Special)	Tonnes	-
Mass of WEC (Steel)	Tonnes	-
WEC Ballast Material		Seawater
WEC Ballast Required	Tonnes	-
WEC PTO Type		Hydraulics
Mooring Line Material		Steel Wire Rope
Anchor Type		Drag Embedment Anchor
Number of Mooring Lines		5
Number of Anchors		5
Distance Offshore	km	20
Number of Tug Boats		3
Towing Speed	knts	2
Project period in years	(don't change)	22
Years of commercial operation	20	

FINANCIAL INPUTS

Choose Discount rate carefully		
FhG 2013: 4 to 7% (actual projects)	% p.a.	8.90
Oxera 2011: 8.9%, UK respondents		
Feed-in Tariff or equivalent		*Paid over max 20 years*
-for Wave Energy	€/MWh	0
- for Floating offshore wind	€/MWh	0

Example: Scotland, first floating wind arrays 2017-18: 3.5 ROC. For fiscal year 2016/2017, 1 ROC = £44.77/MWh and 1£ = 1.15€. This equals 180 €/MWh.

WAVE ENERGY RESOURCE AT THIS SITE

Incident Wave Resource	kW/m	40
- Share of GWh/year from Waves		0.0%
- Share of revenue from Waves		#DIV/0!

POWER OUTPUT CALCULATIONS

PER PLATFORM		
Average WEC Power Output	kW	0
Annual Wave Energy Production	GWh	0.00
Average Wave Power Output (CWF)	kW	0
Annual Wave Energy Production	GWh	0.0
Average Wind Power Output	kW	5760
Annual Wind Energy Production	GWh	50.5
Annual Platform Energy Production	GWh	50.5
- Nominal Full Load Hours per year		5,045
- Nominal (Gross) Capacity Factor		57.6%
Annual revenue from Power sales	€ million	0.00
Platform Rated Power	MW	10.0
- Effective Rated Wave Power	MW	0.0
*- CAPEX per Rated Wave Power **	€/kW	#DIV/0!
FOR THE WHOLE OFFSHORE ENERGY PARK		
Total Park Power Rating	MW	640
Annual Energy Production	GWh	3229.0

Levelised Cost of Energy (LCoE)

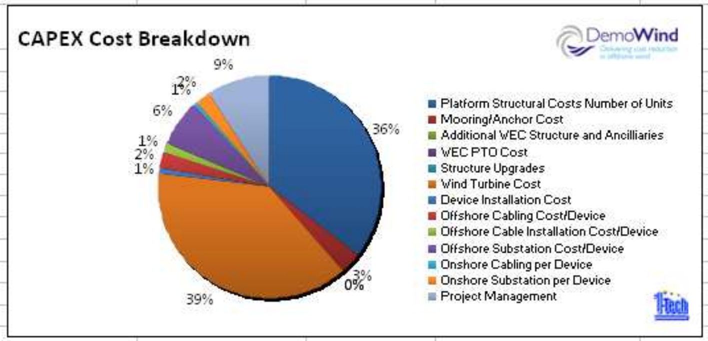
Unit (Platform) CAPEX, on site	EURO €	31,186,358
Discounted Unit Lifetime OPEX	EURO €	6,193,665
OPEX as % of CAPEX		20%
Platform Lifetime Cost	EURO €	37,380,023
Platform Lifetime Energy Productio	GWh	1009.1
LCoE	**€/MWh**	**98.0**
Park CAPEX	€ mln	1996
Park OPEX Discounted	€ mln	396
Park Lifetime Cost (TLC)	€ mln	2392
CAPEX/GWh	€/GWh	618
OPEX/GWh	€/GWh	123
Gross Nominal Revenue, Waves	€ mln	0
Gross Nominal Revenue, Wind	€ mln	0
Net Present Value, NPV	€ million	-2909
Internal Rate of Return, IRR		#DIV/0!

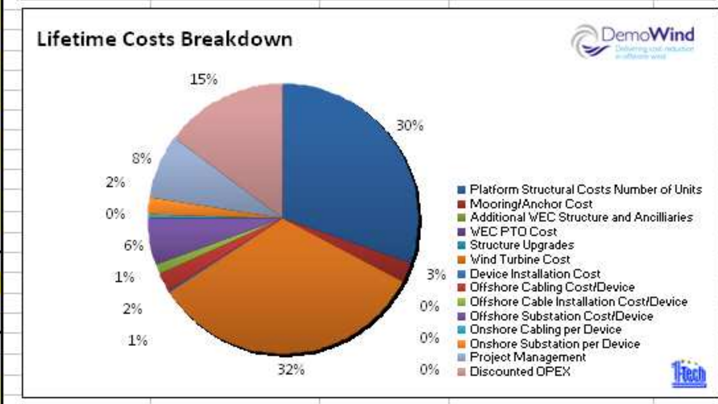
Offshore Renewable Energy Costing and Analysis Tool: ORE-CAT

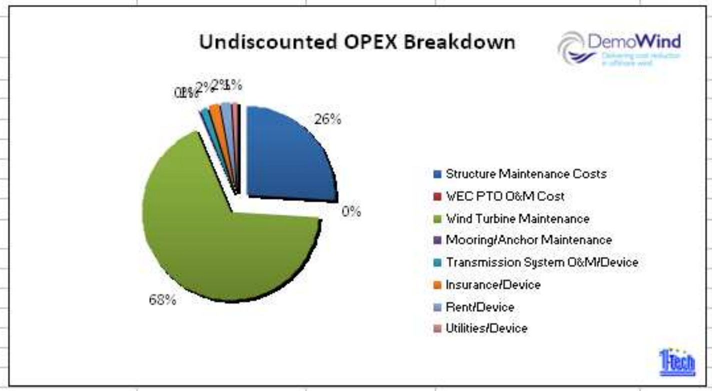
Annex 3: Inputs and Outputs for the cases modelled

b) Argyll Deep site, initial (2017) calculation, "Main" screen 2

COST CALCULATIONS	LIFETIME COST ASSESSMENT			
	10.0 MW PLATFORM		640 MW OFFSHORE ENERGY PARK	
Yard fabrication & construction				
Platform Structural Costs (No. of Units)	EURO€	11,090,990	EURO€	709,823,328
Additional WEC Structure and Ancillaries	EURO€	-	EURO€	-
WEC PTO Cost	EURO€	-	EURO€	-
Wind Turbine Cost (No. of Units)	EURO€	12,000,000	EURO€	768,000,000
Structure Upgrades (for heavy WT's)	EURO€	-	EURO€	-
UNIT (Platform) CAPEX	EURO€	23,090,990	EURO€	1,477,823,328
Off-shore CAPEX breakdown				
Installation Cost at site	EURO€	189,871	EURO€	12,151,734
Mooring/Anchor Cost	EURO€	944,524	EURO€	60,449,528
Offshore Cabling Cost	EURO€	751,563	EURO€	48,100,000
Offshore Cable Installation Cost	EURO€	425,406	EURO€	27,226,000
Offshore Substation Cost	EURO€	2,023,100	EURO€	129,478,400
Onshore Substation	EURO€	750,000	EURO€	48,000,000
Onshore Cabling	EURO€	175,781	EURO€	11,250,000
Off-shore portion of CAPEX		5,260,245	-	336,655,662
Project Management and Contingencies	EURO€	2,835,123	EURO€	181,447,899
Total CAPEX	EURO€	31,186,358	EURO€	1,995,926,889
Total CAPEX/rated power, installed on site	M€/MW	3.12		
OPEX breakdown				
Structure Maintenance Costs	EURO€	8,624,176	EURO€	551,947,264
WEC PTO O&M Cost	EURO€	-	EURO€	-
Wind Turbine Maintenance	EURO€	22,199,616	EURO€	1,420,775,421
Mooring System Maintenance	EURO€	28,336	EURO€	1,813,486
Transmission System O&M	EURO€	431,825	EURO€	27,636,787
Insurance/Device	EURO€	686,100	EURO€	43,910,392
Rent/Device	EURO€	623,727	EURO€	39,918,538
Utilities/Device	EURO€	286,968	EURO€	18,365,952
Undiscounted Lifetime OPEX	EURO€	32,880,747	EURO€	2,104,367,840
Total Lifetime Cost (Undiscounted)	EURO€	64,067,105	EURO€	4,100,294,729







Annex 3: Inputs and Outputs for the cases modelled

c) Argyll Deep site, Updated (2019) calculation, “Main” screen 1

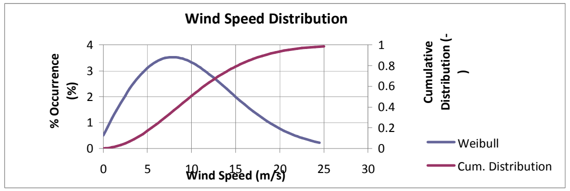
INPUTS (post-2022)

enter data in green cells only
outputs in yellow highlight cells

W2Power "Argyll Deep" development post-2022. Adjusted: WACC 5.5% (AVG 2017). CAPEX WT €1m/MW not 1.2. OPEX - Hull maint. 3% of Capex not 4%. WT maint 100 €/kW not 150. Platform is 12MW TenArray design with 2 x P130-6.0 WT's.

WAVE & WIND PARAMETERS

Specify Wave parameters, or select site:		Specify Incident Resource
Wave Spectral Type		JONSWAP
Significant Wave Height	m	2.38
Average Wave Period	s	12
Always specify Wind resource:		
Average Annual Wind Speed	m/s	10.8
Distribution Function		Weibull
Shape Parameter k		2.0



ENERGY CONVERTERS SPECIFICATIONS

Wave Energy Converters (WEC's):		*(For wind-only, set X = Y = Z = 0m)*
Input Capture Width Factor, or use Reference Device		Reference Device
N/A		75%
Select Reference Device Type		Multiple Point Absorber
WEC X Dimension	m	0
WEC Y Dimension	m	0
WEC Z Dimension	m	0
WEC Capacity/Load Factor		25%
Wind Turbine (-s) used:		
No. of WT's per platform		2
Wind Turbine Type		P6.0-130
Number of Units (=Platforms) in park		54

PLATFORM MASSES

Substructure Hull Mass	Tonnes	2,579.00
WEC Structure Mass	Tonnes	-
Total Ballast (Platform and WEC)	Tonnes	3,300.00
Ancillary Structural Components	Tonnes	-
Structural Upgrades (for some WT's)	Tonnes	-
Substructure Total Mass	Tonnes	5,879.00
Total Mass Substructure + WT/WT's	Tonnes	7,079.00

PLATFORM SPECIFICATIONS

Floating or Fixed Platform		Floating Platform
Platform Stabilisation Method		Buoyancy Stabilised
Water Depth	m	100
Platform Structural Material		Steel Plate
Mass of Platform (Concrete)	Tonnes	-
Mass of Platform (Steel)	Tonnes	2,579.00
Platform Ballast Material		Seawater
Platform Ballast Required	Tonnes	3,300.00
Additional WEC Components Material		Special Concrete / Composite
Mass of WEC (Concrete or Special)	Tonnes	-
Mass of WEC (Steel)	Tonnes	-
WEC Ballast Material		Seawater
WEC Ballast Required	Tonnes	-
WEC PTO Type		Hydraulics
Mooring Line Material		Steel Wire Rope
Anchor Type		Drag Embedment Anchor
Number of Mooring Lines		5
Number of Anchors		5
Distance Offshore	km	20
Number of Tug Boats		3
Towing Speed	knts	2
Project period in years		22
Years of commercial operation	20	

includes allowance 100t/MW for WT (=THM) and towers but varies between turbines

FINANCIAL INPUTS

Choose Discount rate carefully		
FhG 2013: 4 to 7% (actual projects)	% p.a.	5.50
Oxera 2011: 8.9%, UK respondents		
Feed-in Tariff or equivalent		*Paid over max 20 years*
-for Wave Energy	€/MWh	0
- for Floating offshore wind	€/MWh	0

Example: Scotland, first floating wind arrays 2017-18: 3.5 ROC. For fiscal year 2016/2017, 1 ROC = £44.77/MWh and 1£ = 1.15€. This equals 180 €/MWh.

WAVE ENERGY RESOURCE AT THIS SITE

Incident Wave Resource	kW/m	40
- Share of GWh/year from Waves		0.0%
- Share of revenue from Waves		#DIV/0!

POWER OUTPUT CALCULATIONS

PER PLATFORM		
Average WEC Power Output	kW	0
Annual Wave Energy Production	GWh	0.00
Average Wave Power Output (CWF)	kW	0
Annual Wave Energy Production	GWh	0.0
Average Wind Power Output	kW	6832
Annual Wind Energy Production	GWh	59.8
Annual Platform Energy Production	GWh	59.8
- Nominal Full Load Hours per year		4,987
- Nominal (Gross) Capacity Factor		56.9%
Annual revenue from Power sales	€ million	0.00
Platform Rated Power	MW	12.0
- Effective Rated Wave Power	MW	0.0
*- CAPEX per Rated Wave Power **	€/kW	#DIV/0!
FOR THE WHOLE OFFSHORE ENERGY PARK		
Total Park Power Rating	MW	648
Annual Energy Production	GWh	3231.9

Levelised Cost of Energy (LCoE)

Unit (Platform) CAPEX, on site	EURO €	31,958,199
Discounted Unit Lifetime OPEX	EURO €	6,737,517
OPEX as % of CAPEX		21%
Platform Lifetime Cost	EURO €	38,695,716
Platform Lifetime Energy Production	GWh	1197.0
LCoE	**€/MWh**	**64.2**
Park CAPEX	€ mln	1726
Park OPEX Discounted	€ mln	364
Park Lifetime Cost (TLC)	€ mln	2090
CAPEX/GWh	€/GWh	534
OPEX/GWh	€/GWh	113
Gross Nominal Revenue, Waves	€ mln	0
Gross Nominal Revenue, Wind	€ mln	0
Net Present Value, NPV	€ million	-2479
Internal Rate of Return, IRR		#DIV/0!

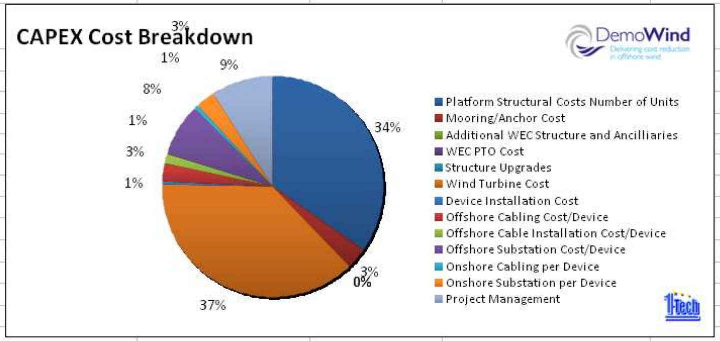
Offshore Renewable Energy Costing and Analysis Tool

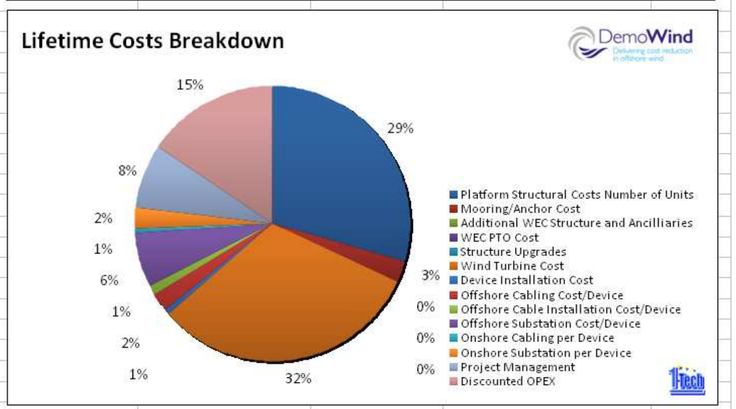
DemoWind
Delivering cost reduction in offshore wind

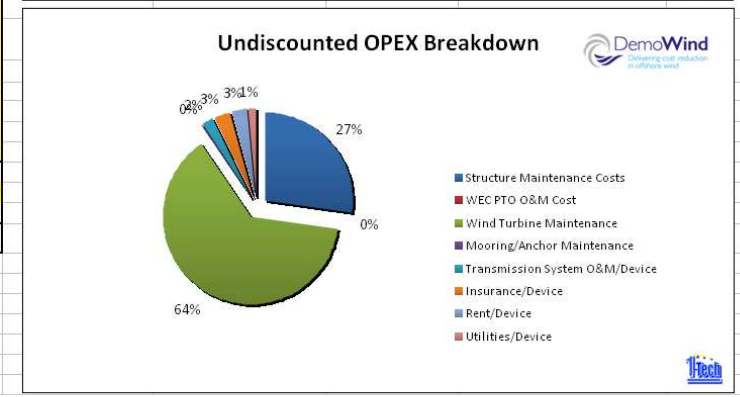
Annex 3: Inputs and Outputs for the cases modelled

d) Argyll Deep site, Updated (2019) calculation, "Main" screen 2

COST CALCULATIONS	LIFETIME COST ASSESSMENT			
	12.0 MW PLATFORM		648 MW OFFSHORE ENERGY PARK	
Yard fabrication & construction				
Platform Structural Costs (No. of Units)	EURO €	11,090,990	EURO €	598,913,433
Additional WEC Structure and Ancillaries	EURO €	-	EURO €	-
WEC PTO Cost	EURO € *	-	EURO €	-
Wind Turbine Cost (No. of Units)	EURO €	12,000,000	EURO €	648,000,000
Structure Upgrades (for heavy WT's)	EURO €	-	EURO €	-
UNIT (Platform) CAPEX	EURO €	23,090,990	EURO €	1,246,913,433
Off-shore CAPEX breakdown				
Installation Cost at site	EURO €	189,871	EURO €	10,253,025
Mooring/Anchor Cost	EURO €	971,985	EURO €	52,487,188
Offshore Cabling Cost	EURO €	816,667	EURO €	44,100,000
Offshore Cable Installation Cost	EURO €	451,963	EURO €	24,406,000
Offshore Substation Cost	EURO €	2,423,100	EURO €	130,847,400
Onshore Substation	EURO €	900,000	EURO €	48,600,000
Onshore Cabling	EURO €	208,333	EURO €	11,250,000
Off-shore portion of CAPEX		5,961,919	-	321,943,613
Project Management and Contingencies	EURO €	2,905,291	EURO €	156,885,705
Total CAPEX	EURO €	31,958,199	EURO €	1,725,742,751
Total CAPEX/rated power, installed on sit	M€/MW	2.66		
OPEX breakdown, over project period		*undiscounted*		*undiscounted*
Structure Maintenance Costs	EURO €	6,468,132	EURO €	349,279,128
WEC PTO O&M Cost	EURO €	-	EURO €	-
Wind Turbine Maintenance	EURO €	14,962,375	EURO €	807,968,244
Mooring System Maintenance	EURO €	29,160	EURO €	1,574,616
Transmission System O&M	EURO €	503,887	EURO €	27,209,899
Insurance/Device	EURO €	703,080	EURO €	37,966,341
Rent/Device	EURO €	639,164	EURO €	34,514,855
Utilities/Device	EURO €	344,362	EURO €	18,595,526
Undiscounted Lifetime OPEX	EURO €	23,650,159	EURO €	1,277,108,609
Total Lifetime Cost (Undiscounted)	EURO €	55,608,359	EURO €	3,002,851,359







Annex 3: Inputs and Outputs for the cases modelled

e) Utsira II site, Initial (2017) calculation, “Main” screen 1

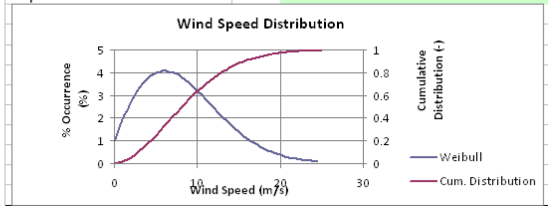
INPUTS

enter data in green cells only
outputs in yellow highlight cells

W2Power wind-only with 64 2x5-MW platforms. Data for Utsira II general area (MARINA Platform), not optimised for specific siting. Nearest major port (Haugesund) sailing distance about 20 km. At 6% WACC LCoE becomes 101.1 €/MWh

WAVE & WIND PARAMETERS

Specify Wave parameters, or select site:		Specify Incident Resource
Wave Spectral Type		JONSWAP
Significant Wave Height	m	2.18
Average Wave Period	s	12.29
Always specify Wind resource:		
Average Annual Wind Speed	m/s	9.03
Distribution Function		Weibull
Shape Parameter k		1.9



ENERGY CONVERTERS SPECIFICATIONS

Wave Energy Converters (WEC's):		*(For wind-only, set X = Y = Z = 0m)*
Input Capture Width Factor, or use Reference Device		Reference Device
N/A		75%
Select Reference Device Type		Multiple Point Absorber
WEC X Dimension	m	0
WEC Y Dimension	m	0
WEC Z Dimension	m	0
WEC Capacity/Load Factor		25%
Wind Turbine (-s) used:		
No. of WT's per platform		2
Wind Turbine Type		NREL 5MW
Number of Units (=Platforms) in park		64

PLATFORM MASSES

Substructure Hull Mass	Tonnes	2,579.00
WEC Structure Mass	Tonnes	-
Total Ballast (Platform and WEC)	Tonnes	3,300.00
Ancillary Structural Components	Tonnes	-
Structural Upgrades (for some WT's)	Tonnes	-
Substructure Total Mass	Tonnes	5,879.00
Total Mass Substructure + WT/WT's	Tonnes	6,879.00

PLATFORM SPECIFICATIONS

Floating or Fixed Platform		Floating Platform
Platform Stabilisation Method		Buoyancy Stabilised
Water Depth	m	220
Platform Structural Material		Steel Plate
Mass of Platform (Concrete)	Tonnes	-
Mass of Platform (Steel)	Tonnes	2,579.00
Platform Ballast Material		Seawater
Platform Ballast Required	Tonnes	3,300.00
Additional WEC Components Material		Special Concrete / Composite
Mass of WEC (Concrete or Special)	Tonnes	-
Mass of WEC (Steel)	Tonnes	-
WEC Ballast Material		Seawater
WEC Ballast Required	Tonnes	-
WEC PTO Type		Hydraulics
Mooring Line Material		Steel Wire Rope
Anchor Type		Drag Embedment Anchor
Number of Mooring Lines		5
Number of Anchors		5
Distance Offshore	km	20
Number of Tug Boats		3
Towing Speed	knts	2
Project period in years	(don't change)	22
Years of commercial operation	20	

includes allowance 100t/MW for WT (=THM) and towers but varies between turbines

FINANCIAL INPUTS

Choose Discount rate carefully		
FhG 2013: 4 to 7% (actual projects)	% p.a.	8.90
Oxera 2011: 8.9%, UK respondents		
Feed-in Tariff or equivalent		*Paid over max 20 years*
-for Wave Energy	€/MWh	0
-for Floating offshore wind	€/MWh	0

Example: Scotland, first floating wind arrays 2017-18: 3.5 ROC. For fiscal year 2016/2017, 1 ROC = £44.77/MWh and 1£ = 1.15€. This equals 180 €/MWh.

WAVE ENERGY RESOURCE AT THIS SITE

Incident Wave Resource	kW/m	34
- Share of GWh/year from Waves		0.0%
- Share of revenue from Waves		#DIV/0!

POWER OUTPUT CALCULATIONS

PER PLATFORM		
Average WEC Power Output	kW	0
Annual Wave Energy Production	GWh	0.00
Average Wave Power Output (CWF)	kW	0
Annual Wave Energy Production	GWh	0.0
Average Wind Power Output	kW	4670
Annual Wind Energy Production	GWh	40.9
Annual Platform Energy Production	GWh	40.9
- Nominal Full Load Hours per year		4,091
- Nominal (Gross) Capacity Factor		46.7%
Annual revenue from Power sales	€ million	0.00
Platform Rated Power	MW	10.0
- Effective Rated Wave Power	MW	0.0
- CAPEX per Rated Wave Power *	€/kW	#DIV/0!
FOR THE WHOLE OFFSHORE ENERGY PARK		
Total Park Power Rating	MW	640
Annual Energy Production	GWh	2618.3

Levelised Cost of Energy (LCoE)

Unit (Platform) CAPEX, on site	EURO €	31,530,751
Discounted Unit Lifetime OPEX	EURO €	5,407,217
OPEX as % of CAPEX		17%
Platform Lifetime Cost	EURO €	36,937,969
Platform Lifetime Energy Productio	GWh	818.2
LCoE	**€/MWh**	**117.2**
Park CAPEX	€ mln	2018
Park OPEX Discounted	€ mln	346
Park Lifetime Cost (TLC)	€ mln	2364
CAPEX/GWh	€/GWh	771
OPEX/GWh	€/GWh	132
Gross Nominal Revenue, Waves	€ mln	0
Gross Nominal Revenue, Wind	€ mln	0
Net Present Value, NPV	€ million	-2821
Internal Rate of Return, IRR		#DIV/0!

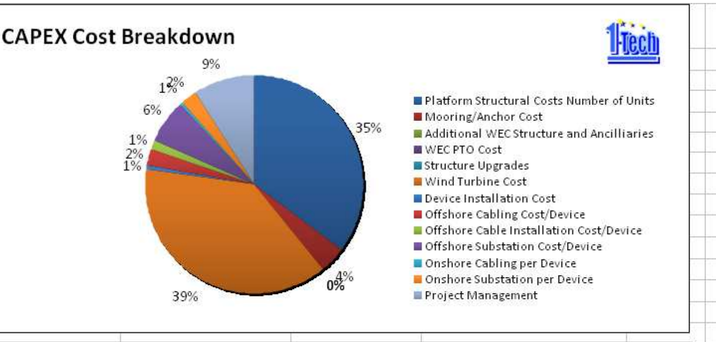
Offshore Renewable Energy Costing and Analysis Tool

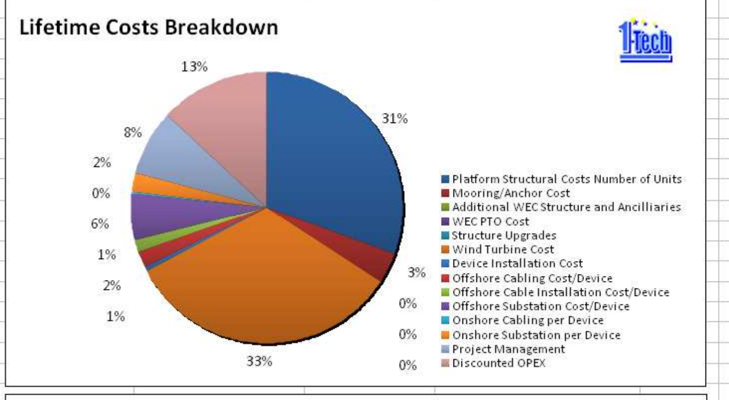
Annex 3: Inputs and Outputs for the cases modelled

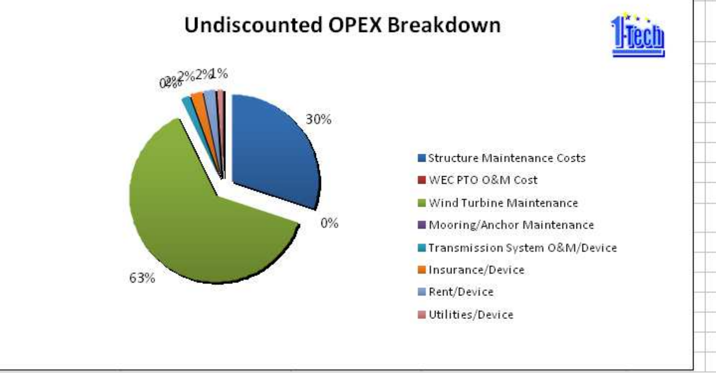
f) Utsira II site, Initial (2017) calculation, "Main" screen 2

COST CALCULATIONS	LIFETIME COST ASSESSMENT			
		10.0 MW PLATFORM		640 MW OFFSHORE ENERGY PARK
Yard fabrication & construction				
Platform Structural Costs (No.of Units)	EURO €	11,090,990	EURO €	709,823,328
Additional WEC Structure and Ancillaries	EURO €	-	EURO €	-
WEC PTO Cost	EURO € *	-	EURO €	-
Wind Turbine Cost (Number of Units)	EURO €	12,000,000	EURO €	768,000,000
Structure Upgrades (for heavy WT's)	EURO €	-	EURO €	-
UNIT (Platform) CAPEX	EURO €	23,090,990	EURO €	1,477,823,328
Off-shore CAPEX breakdown				
Installation Cost at site	EURO €	189,871	EURO €	12,151,734
Mooring/Anchor Cost	EURO €	1,257,609	EURO €	80,486,981
Offshore Cabling Cost	EURO €	751,563	EURO €	48,100,000
Offshore Cable Installation Cost	EURO €	425,406	EURO €	27,226,000
Offshore Substation Cost	EURO €	2,023,100	EURO €	129,478,400
Onshore Substation	EURO €	750,000	EURO €	48,000,000
Onshore Cabling	EURO €	175,781	EURO €	11,250,000
Off-shore portion of CAPEX		5,573,330	-	356,693,115
Project Management and Contingencies	EURO €	2,866,432	EURO €	183,451,644
Total CAPEX	EURO €	31,530,751	EURO €	2,017,968,087
Total CAPEX/rated power, installed on sit	M€/MW	3.15		
OPEX breakdown				
Structure Maintenance Costs	EURO €	8,624,176	EURO €	551,947,264
WEC PTO O&M Cost	EURO €	-	EURO €	-
Wind Turbine Maintenance	EURO €	18,000,688	EURO €	1,152,044,013
Mooring System Maintenance	EURO €	37,728	EURO €	2,414,609
Transmission System O&M	EURO €	431,825	EURO €	27,636,787
Insurance/Device	EURO €	693,677	EURO €	44,395,298
Rent/Device	EURO €	630,615	EURO €	40,359,362
Utilities/Device	EURO €	286,968	EURO €	18,365,952
Undiscounted Lifetime OPEX	EURO €	28,705,676	EURO €	1,837,163,286
Total Lifetime Cost (Undiscounted)	EURO €	60,236,428	EURO €	3,855,131,373

DemoWind
Delivering cost reduction in offshore wind







Annex 3: Inputs and Outputs for the cases modelled

g) Utsira II site, Updated (2019) calculation, “Main” screen 1

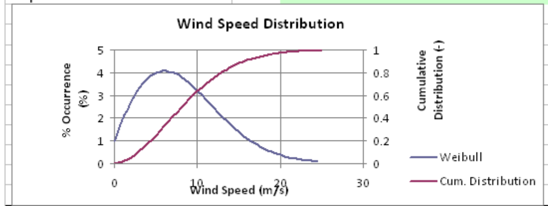
INPUTS (post-2022)

enter data in green cells only
outputs in yellow highlight cells

W2Power "Utsira II site, 220m post-2022 devel. Adjusted: WACC 5.5% (AVG 2017). CAPEX WT €1m/MW not 1.2. OPEX - Hull maint. 3% of Capex not 4%. WT maint 100 €/kW not 150. Platform is 12MW TenArray design with 2 x P130-6.0 WT's.

WAVE & WIND PARAMETERS

Specify Wave parameters, or select site:		Specify Incident Resource
Wave Spectral Type		JONSWAP
Significant Wave Height	m	2.18
Average Wave Period	s	12.3
Always specify Wind resource:		
Average Annual Wind Speed	m/s	9.03
Distribution Function		Weibull
Shape Parameter k		1.9



ENERGY CONVERTERS SPECIFICATIONS

Wave Energy Converters (WEC's):		*(For wind-only, set X = Y = Z = 0m)*
Input Capture Width Factor, or use Reference Device		Reference Device
N/A		75%
Select Reference Device Type		Multiple Point Absorber
WEC X Dimension	m	0
WEC Y Dimension	m	0
WEC Z Dimension	m	0
WEC Capacity/Load Factor		25%
Wind Turbine (-s) used:		
No. of WT's per platform		2
Wind Turbine Type		P6.0-130
Number of Units (=Platforms) in park		54

PLATFORM MASSES

Substructure Hull Mass	Tonnes	2,579.00
WEC Structure Mass	Tonnes	-
Total Ballast (Platform and WEC)	Tonnes	3,300.00
Ancillary Structural Components	Tonnes	-
Structural Upgrades (for some WT's)	Tonnes	-
Substructure Total Mass	Tonnes	5,879.00
Total Mass Substructure + WT/WT's	Tonnes	7,079.00

includes allowance 100t/MW for WT (=THM) and towers but varies between turbines

PLATFORM SPECIFICATIONS

Floating or Fixed Platform		Floating Platform
Platform Stabilisation Method		Buoyancy Stabilised
Water Depth	m	220
Platform Structural Material		Steel Plate
Mass of Platform (Concrete)	Tonnes	-
Mass of Platform (Steel)	Tonnes	2,579.00
Platform Ballast Material		Seawater
Platform Ballast Required	Tonnes	3,300.00
Additional WEC Components Material		Special Concrete / Composite
Mass of WEC (Concrete or Special)	Tonnes	-
Mass of WEC (Steel)	Tonnes	-
WEC Ballast Material		Seawater
WEC Ballast Required	Tonnes	-
WEC PTO Type		Hydraulics
Mooring Line Material		Steel Wire Rope
Anchor Type		Drag Embedment Anchor
Number of Mooring Lines		5
Number of Anchors		5
Distance Offshore	km	20
Number of Tug Boats		3
Towing Speed	knts	2
Project period in years	(don't change)	22
Years of commercial operation	20	

FINANCIAL INPUTS

Choose Discount rate carefully		
FhG 2013: 4 to 7% (actual projects)	% p.a.	5.50
Oxera 2011: 8.9%, UK respondents		
Feed-in Tariff or equivalent		*Paid over max 20 years*
-for Wave Energy	€/MWh	0
- for Floating offshore wind	€/MWh	0

Example: Scotland, first floating wind arrays 2017-18: 3.5 ROC. For fiscal year 2016/2017, 1 ROC = £44.77/MWh and 1£ = 1.15€. This equals 180 €/MWh.

WAVE ENERGY RESOURCE AT THIS SITE

Incident Wave Resource	kW/m	34
- Share of GWh/year from Waves		0.0%
- Share of revenue from Waves		#DIV/0!

POWER OUTPUT CALCULATIONS

PER PLATFORM		
Average WEC Power Output	kW	0
Annual Wave Energy Production	GWh	0.00
Average Wave Power Output (CWF)	kW	0
Annual Wave Energy Production	GWh	0.0
Average Wind Power Output	kW	5523
Annual Wind Energy Production	GWh	48.4
Annual Platform Energy Production	GWh	48.4
- Nominal Full Load Hours per year		4,032
- Nominal (Gross) Capacity Factor		46.0%
Annual revenue from Power sales	€ million	0.00
Platform Rated Power	MW	12.0
- Effective Rated Wave Power	MW	0.0
*- CAPEX per Rated Wave Power **	€/kW	#DIV/0!
FOR THE WHOLE OFFSHORE ENERGY PARK		
Total Park Power Rating	MW	648
Annual Energy Production	GWh	2612.8

Levelised Cost of Energy (LCoE)

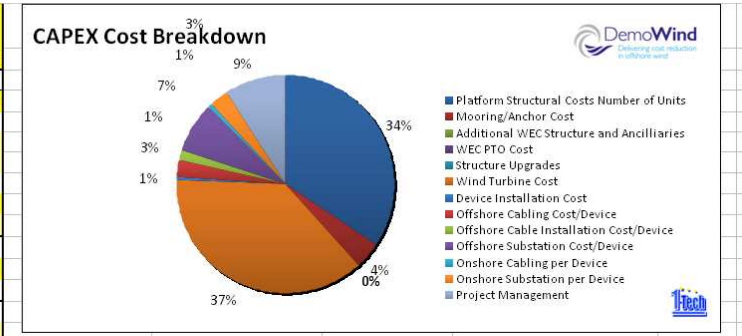
Unit (Platform) CAPEX, on site	EURO €	32,312,606
Discounted Unit Lifetime OPEX	EURO €	6,272,645
OPEX as % of CAPEX		19%
Platform Lifetime Cost	EURO €	38,585,251
Platform Lifetime Energy Productio	GWh	967.7
LCoE	**€/MWh**	**78.5**
Park CAPEX	€ mln	1745
Park OPEX Discounted	€ mln	339
Park Lifetime Cost (TLC)	€ mln	2084
CAPEX/GWh	€/GWh	668
OPEX/GWh	€/GWh	130
Gross Nominal Revenue, Waves	€ mln	0
Gross Nominal Revenue, Wind	€ mln	0
Net Present Value, NPV	€ million	-2451
Internal Rate of Return, IRR		#DIV/0!

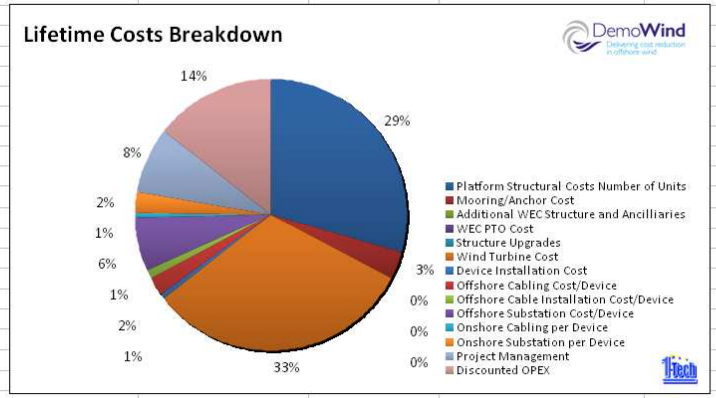
Offshore Renewable Energy Costing and Analysis Tool

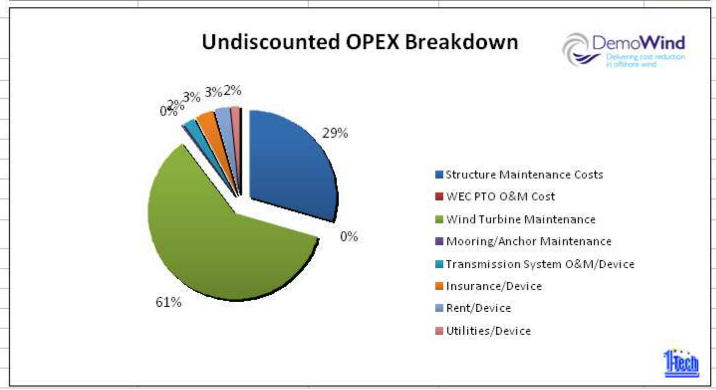
Annex 3: Inputs and Outputs for the cases modelled

h) Utsira II site, Updated (2019) calculation, "Main" screen 2

COST CALCULATIONS	LIFETIME COST ASSESSMENT			
		12.0 MW PLATFORM		648 MW OFFSHORE ENERGY PARK
Yard fabrication & construction				
Platform Structural Costs (No. of Units)	EURO €	11,090,990	EURO €	598,913,433
Additional WEC Structure and Ancillaries	EURO €	-	EURO €	-
WEC PTO Cost	EURO € *	-	EURO €	-
Wind Turbine Cost (No. of Units)	EURO €	12,000,000	EURO €	648,000,000
Structure Upgrades (for heavy WT's)	EURO €	-	EURO €	-
UNIT (Platform) CAPEX	EURO €	23,090,990	EURO €	1,246,913,433
Off-shore CAPEX breakdown				
Installation Cost at site	EURO €	189,871	EURO €	10,253,025
Mooring/Anchor Cost	EURO €	1,294,173	EURO €	69,885,331
Offshore Cabling Cost	EURO €	816,667	EURO €	44,100,000
Offshore Cable Installation Cost	EURO €	451,963	EURO €	24,406,000
Offshore Substation Cost	EURO €	2,423,100	EURO €	130,847,400
Onshore Substation	EURO €	900,000	EURO €	48,600,000
Onshore Cabling	EURO €	208,333	EURO €	11,250,000
Off-shore portion of CAPEX		6,284,107	-	339,341,756
Project Management and Contingencies	EURO €	2,937,510	EURO €	158,625,519
Total CAPEX	EURO €	32,312,606	EURO €	1,744,880,708
Total CAPEX/rated power, installed on sit	M€/MW	2.69		
		undiscounted		*undiscounted*
OPEX breakdown, over project period				
Structure Maintenance Costs	EURO €	6,468,132	EURO €	349,279,128
WEC PTO O&M Cost	EURO €	-	EURO €	-
Wind Turbine Maintenance	EURO €	13,306,023	EURO €	718,525,242
Mooring System Maintenance	EURO €	38,825	EURO €	2,096,560
Transmission System O&M	EURO €	503,887	EURO €	27,209,899
Insurance/Device	EURO €	710,877	EURO €	38,387,376
Rent/Device	EURO €	646,252	EURO €	34,897,614
Utilities/Device	EURO €	344,362	EURO €	18,595,526
Undiscounted Lifetime OPEX	EURO €	22,018,358	EURO €	1,188,991,346
Total Lifetime Cost (Undiscounted)	EURO €	54,330,964	EURO €	2,933,872,054







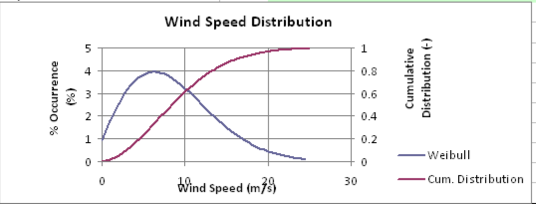
Annex 3: Inputs and Outputs for the cases modelled

i) Alboran Sea site, Initial (2017) calculation, “Main” screen 1

INPUTS	
enter data in green cells only	W2Power wind-only with 64 2x5-MW platforms. Data for "Mar de Alborán" site. Sailing distance from major port c. 30 km.
outputs in yellow highlight cells	At 6% WACC, the LCoE becomes 98 €/MWh

WAVE & WIND PARAMETERS

Specify Wave parameters, or select site:		Specify Incident Resource
Wave Spectral Type		JONSWAP
Significant Wave Height	m	1.0
Average Wave Period	s	6.0
Always specify Wind resource:		
Average Annual Wind Speed	m/s	9.33
Distribution Function		Weibull
Shape Parameter k		1.88



ENERGY CONVERTERS SPECIFICATIONS

Wave Energy Converters (WEC's):		(For wind-only, set X = Y = Z = 0m)
Input Capture Width Factor, or use Reference Device		Reference Device
N/A		75%
Select Reference Device Type		Multiple Point Absorber
WEC X Dimension	m	0
WEC Y Dimension	m	0
WEC Z Dimension	m	0
WEC Capacity/Load Factor		25%
Wind Turbine (-s) used:		
No. of WT's per platform		2
Wind Turbine Type		NREL 5MW
Number of Units (=Platforms) in park		64

PLATFORM MASSES

Substructure Hull Mass	Tonnes	2,579.00
WEC Structure Mass	Tonnes	-
Total Ballast (Platform and WEC)	Tonnes	3,300.00
Ancillary Structural Components	Tonnes	-
Structural Upgrades (for some WT's)	Tonnes	-
Substructure Total Mass	Tonnes	5,879.00
Total Mass Substructure + WT/WT's	Tonnes	6,879.00

PLATFORM SPECIFICATIONS

Floating or Fixed Platform		Floating Platform
Platform Stabilisation Method		Buoyancy Stabilised
Water Depth	m	100
Platform Structural Material		Steel Plate
Mass of Platform (Concrete)	Tonnes	-
Mass of Platform (Steel)	Tonnes	2,579.00
Platform Ballast Material		Seawater
Platform Ballast Required	Tonnes	3,300.00
Additional WEC Components Material		Special Concrete / Composite
Mass of WEC (Concrete or Special)	Tonnes	-
Mass of WEC (Steel)	Tonnes	-
WEC Ballast Material		Seawater
WEC Ballast Required	Tonnes	-
WEC PTO Type		Hydraulics
Mooring Line Material		Steel Wire Rope
Anchor Type		Drag Embedment Anchor
Number of Mooring Lines		5
Number of Anchors		5
Distance Offshore	km	30
Number of Tug Boats		3
Towing Speed	knts	2
Project period in years		22
Years of commercial operation	20	

includes allowance 100t/MW for WT (=THM) and towers but varies between turbines

FINANCIAL INPUTS

Choose Discount rate carefully		
FhG 2013: 4 to 7% (actual projects)	% p.a.	8.90
Oxera 2011: 8.9%, UK respondents		
Feed-in Tariff or equivalent		Paid over max 20 years
-for Wave Energy	€/MWh	0
-for Floating offshore wind	€/MWh	0

Example: Scotland, first floating wind arrays 2017-18: 3.5 ROC. For fiscal year 2016/2017, 1 ROC = £44.77/MWh and 1£ = 1.15€. This equals 180 €/MWh.

WAVE ENERGY RESOURCE AT THIS SITE

Incident Wave Resource	kW/m	4
- Share of GWh/year from Waves		0.0%
- Share of revenue from Waves		#DIV/0!

POWER OUTPUT CALCULATIONS

PER PLATFORM		
Average WEC Power Output	kW	0
Annual Wave Energy Production	GWh	0.00
Average Wave Power Output (CWF)	kW	0
Annual Wave Energy Production	GWh	0.0
Average Wind Power Output	kW	4857
Annual Wind Energy Production	GWh	42.5
Annual Platform Energy Production	GWh	42.5
- Nominal Full Load Hours per year		4,255
- Nominal (Gross) Capacity Factor		48.6%
Annual revenue from Power sales	€ million	0.00
Platform Rated Power	MW	10.0
- Effective Rated Wave Power	MW	0.0
- CAPEX per Rated Wave Power *	€/kW	#DIV/0!
FOR THE WHOLE OFFSHORE ENERGY PARK		
Total Park Power Rating	MW	640
Annual Energy Production	GWh	2723.1

Levelised Cost of Energy (LCoE)

Unit (Platform) CAPEX, on site	EURO €	31,521,429
Discounted Unit Lifetime OPEX	EURO €	5,545,381
OPEX as % of CAPEX		18%
Platform Lifetime Cost	EURO €	37,066,810
Platform Lifetime Energy Productio	GWh	851.0
LCoE	**€/MWh**	**113.4**
Park CAPEX	€ mln	2017
Park OPEX Discounted	€ mln	355
Park Lifetime Cost (TLC)	€ mln	2372
CAPEX/GWh	€/GWh	741
OPEX/GWh	€/GWh	130
Gross Nominal Revenue, Waves	€ mln	0
Gross Nominal Revenue, Wind	€ mln	0
Net Present Value, NPV	€ million	-2840
Internal Rate of Return, IRR		#DIV/0!

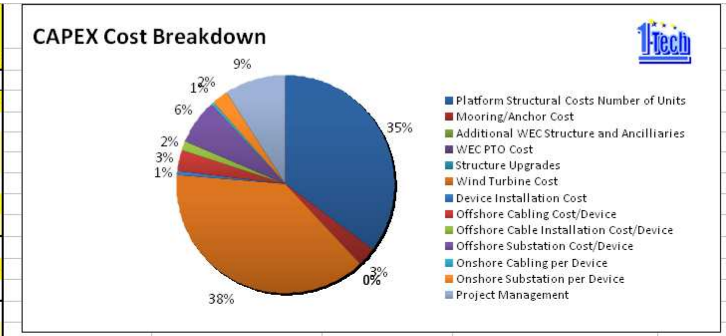
Offshore Renewable Energy Costing and Analysis Tool

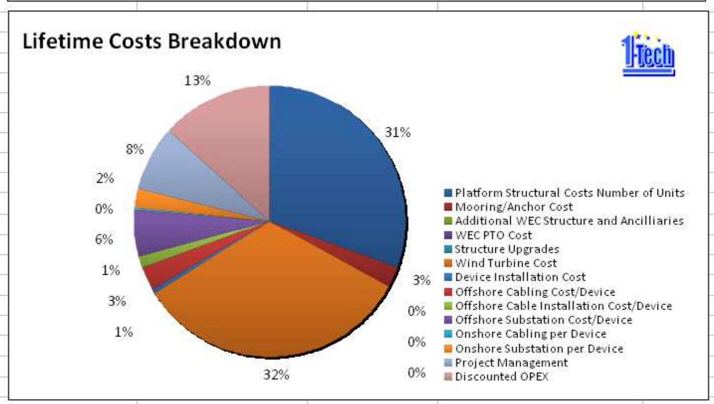
Annex 3: Inputs and Outputs for the cases modelled

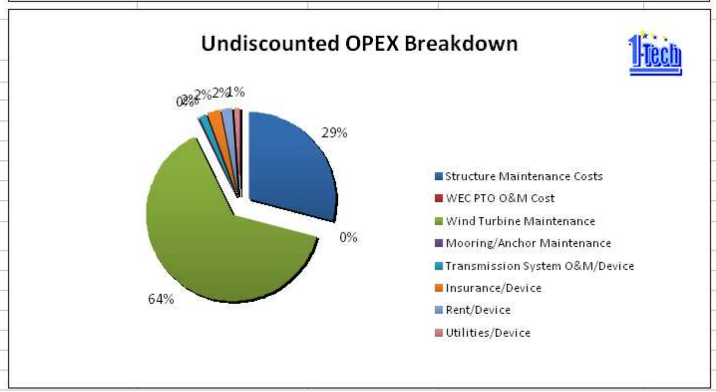
j) Alboran Sea site, Initial (2017) calculation, "Main" screen 2

COST CALCULATIONS	LIFETIME COST ASSESSMENT			
	10.0 MW PLATFORM		640 MW OFFSHORE ENERGY PARK	
Yard fabrication & construction				
Platform Structural Costs (No.of Units)	EURO €	11,090,990	EURO €	709,823,328
Additional WEC Structure and Ancillaries	EURO €	-	EURO €	-
WEC PTO Cost	EURO € *	-	EURO €	-
Wind Turbine Cost (Number of Units)	EURO €	12,000,000	EURO €	768,000,000
Structure Upgrades (for heavy WT's)	EURO €	-	EURO €	-
UNIT (Platform) CAPEX	EURO €	23,090,990	EURO €	1,477,823,328
Off-shore CAPEX breakdown				
Installation Cost at site	EURO €	241,056	EURO €	15,427,601
Mooring/Anchor Cost	EURO €	944,524	EURO €	60,449,528
Offshore Cabling Cost	EURO €	927,344	EURO €	59,350,000
Offshore Cable Installation Cost	EURO €	491,500	EURO €	31,456,000
Offshore Substation Cost	EURO €	2,034,650	EURO €	130,217,600
Onshore Substation	EURO €	750,000	EURO €	48,000,000
Onshore Cabling	EURO €	175,781	EURO €	11,250,000
Off-shore portion of CAPEX		5,564,855	-	356,150,729
Project Management and Contingencies	EURO €	2,865,584	EURO €	183,397,406
Total CAPEX	EURO €	31,521,429	EURO €	2,017,371,462
Total CAPEX/rated power, installed on sit	M€/MW	3.15		
OPEX breakdown				
Structure Maintenance Costs	EURO €	8,624,176	EURO €	551,947,264
WEC PTO O&M Cost	EURO €	-	EURO €	-
Wind Turbine Maintenance	EURO €	18,721,647	EURO €	1,198,185,410
Mooring System Maintenance	EURO €	28,336	EURO €	1,813,486
Transmission System O&M	EURO €	454,126	EURO €	29,064,077
Insurance/Device	EURO €	693,471	EURO €	44,382,172
Rent/Device	EURO €	630,429	EURO €	40,347,429
Utilities/Device	EURO €	286,968	EURO €	18,365,952
Undiscounted Lifetime OPEX	EURO €	29,439,153	EURO €	1,884,105,790
Total Lifetime Cost (Undiscounted)	EURO €	60,960,582	EURO €	3,901,477,252

DemoWind
Delivering cost reduction in offshore wind







Annex 3: Inputs and Outputs for the cases modelled

k) Alboran Sea site, Updated (2019) calculation, "Main" screen 1

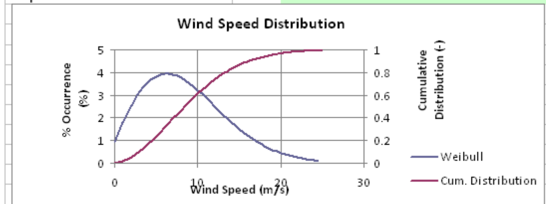
INPUTS (post-2022)

enter data in green cells only
outputs in yellow highlight cells

W2Power "Alboran Sea" dev post-2022 for EO biz plan. Adjusted: WACC 5.5% (AVG 2017). CAPEX WT €1m/MW not 1.2. OPEX - Hull maint. 3% of Capex not 4%. WT maint 100 €/kW not 150. Platform is 12MW TenArray design **with 2 x P130-6.0 WT's.**

WAVE & WIND PARAMETERS

Specify Wave parameters, or select site:		Specify Incident Resource
Wave Spectral Type		JONSWAP
Significant Wave Height	m	1
Average Wave Period	s	6
Always specify Wind resource:		
Average Annual Wind Speed	m/s	9.33
Distribution Function		Weibull
Shape Parameter k		1.9



ENERGY CONVERTERS SPECIFICATIONS

Wave Energy Converters (WEC's):		*(For wind-only, set X = Y = Z = 0m)*
Input Capture Width Factor, or use Reference Device		Reference Device
N/A		75%
Select Reference Device Type		Multiple Point Absorber
WEC X Dimension	m	0
WEC Y Dimension	m	0
WEC Z Dimension	m	0
WEC Capacity/Load Factor		25%
Wind Turbine (-s) used:		
No. of WT's per platform		2
Wind Turbine Type		P6.0-130
Number of Units (=Platforms) in park		54

PLATFORM MASSES

Substructure Hull Mass	Tonnes	2,579.00
WEC Structure Mass	Tonnes	-
Total Ballast (Platform and WEC)	Tonnes	3,300.00
Ancillary Structural Components	Tonnes	-
Structural Upgrades (for some WT's)	Tonnes	-
Substructure Total Mass	Tonnes	5,879.00
Total Mass Substructure + WT/WT's	Tonnes	7,079.00

includes allowance 100t/MW for WT (=THM) and towers but varies between turbines

PLATFORM SPECIFICATIONS

Floating or Fixed Platform		Floating Platform
Platform Stabilisation Method		Buoyancy Stabilised
Water Depth	m	100
Platform Structural Material		Steel Plate
Mass of Platform (Concrete)	Tonnes	-
Mass of Platform (Steel)	Tonnes	2,579.00
Platform Ballast Material		Seawater
Platform Ballast Required	Tonnes	3,300.00
Additional WEC Components Material		Special Concrete / Composite
Mass of WEC (Concrete or Special)	Tonnes	-
Mass of WEC (Steel)	Tonnes	-
WEC Ballast Material		Seawater
WEC Ballast Required	Tonnes	-
WEC PTO Type		Hydraulics
Mooring Line Material		Steel Wire Rope
Anchor Type		Drag Embedment Anchor
Number of Mooring Lines		5
Number of Anchors		5
Distance Offshore	km	30
Number of Tug Boats		3
Towing Speed	knts	2
Project period in years		22
Years of commercial operation	20	

FINANCIAL INPUTS

Choose Discount rate carefully		
FhG 2013: 4 to 7% (actual projects)	% p.a.	5.50
Oxera 2011: 8.9%, UK respondents		
Feed-in Tariff or equivalent		*Paid over max 20 years*
-for Wave Energy	€/MWh	0
- for Floating offshore wind	€/MWh	0

Example: Scotland, first floating wind arrays 2017-18: 3.5 ROC. For fiscal year 2016/2017, 1 ROC = £44.77/MWh and 1£ = 1.15€. This equals 180 €/MWh.

WAVE ENERGY RESOURCE AT THIS SITE

Incident Wave Resource	kW/m	4
- Share of GWh/year from Waves		0.0%
- Share of revenue from Waves		#DIV/0!

POWER OUTPUT CALCULATIONS

PER PLATFORM		
Average WEC Power Output	kW	0
Annual Wave Energy Production	GWh	0.00
Average Wave Power Output (CWF)	kW	0
Annual Wave Energy Production	GWh	0.0
Average Wind Power Output	kW	5748
Annual Wind Energy Production	GWh	50.4
Annual Platform Energy Production	GWh	50.4
- Nominal Full Load Hours per year		4,196
- Nominal (Gross) Capacity Factor		47.9%
Annual revenue from Power sales	€ million	0.00
Platform Rated Power	MW	12.0
- Effective Rated Wave Power	MW	0.0
- CAPEX per Rated Wave Power *	€/kW	#DIV/0!
FOR THE WHOLE OFFSHORE ENERGY PARK		
Total Park Power Rating	MW	648
Annual Energy Production	GWh	2719.2

Levelised Cost of Energy (LCoE)

Unit (Platform) CAPEX, on site	EURO €	32,342,541
Discounted Unit Lifetime OPEX	EURO €	6,432,063
OPEX as % of CAPEX		20%
Platform Lifetime Cost	EURO €	38,774,604
Platform Lifetime Energy Productio	GWh	1007.1
LCoE	**€/MWh**	**76.0**
Park CAPEX	€ mln	1746
Park OPEX Discounted	€ mln	347
Park Lifetime Cost (TLC)	€ mln	2094
CAPEX/GWh	€/GWh	642
OPEX/GWh	€/GWh	128
Gross Nominal Revenue, Waves	€ mln	0
Gross Nominal Revenue, Wind	€ mln	0
Net Present Value, NPV	€ million	-2470
Internal Rate of Return, IRR		#DIV/0!

Offshore Renewable Energy Costing and Analysis Tool

DemoWind Delivering cost reduction in offshore wind

Annex 3: Inputs and Outputs for the cases modelled

I) Alboran Sea site, Updated (2019) calculation, “Main” screen 2

COST CALCULATIONS	LIFETIME COST ASSESSMENT			
		12.0 MW PLATFORM		648 MW OFFSHORE ENERGY PARK
Yard fabrication & construction				
Platform Structural Costs (No. of Units)	EURO €	11,090,990	EURO €	598,913,433
Additional WEC Structure and Ancillaries	EURO €	-	EURO €	-
WEC PTO Cost	EURO € *	-	EURO €	-
Wind Turbine Cost (No. of Units)	EURO €	12,000,000	EURO €	648,000,000
Structure Upgrades (for heavy WT's)	EURO €	-	EURO €	-
UNIT (Platform) CAPEX	EURO €	23,090,990	EURO €	1,246,913,433
Off-shore CAPEX breakdown				
Installation Cost at site	EURO €	241,056	EURO €	13,017,038
Mooring/Anchor Cost	EURO €	971,985	EURO €	52,487,188
Offshore Cabling Cost	EURO €	1,025,000	EURO €	55,350,000
Offshore Cable Installation Cost	EURO €	530,296	EURO €	28,636,000
Offshore Substation Cost	EURO €	2,434,650	EURO €	131,471,100
Onshore Substation	EURO €	900,000	EURO €	48,600,000
Onshore Cabling	EURO €	208,333	EURO €	11,250,000
Off-shore portion of CAPEX		6,311,321	-	340,811,326
Project Management and Contingencies	EURO €	2,940,231	EURO €	158,772,476
Total CAPEX	EURO €	32,342,541	EURO €	1,746,497,235
Total CAPEX/rated power, installed on sit	M€/MW	2.70		
OPEX breakdown, over project period		*undiscounted*		*undiscounted*
Structure Maintenance Costs	EURO €	6,468,132	EURO €	349,279,128
WEC PTO O&M Cost	EURO €	-	EURO €	-
Wind Turbine Maintenance	EURO €	13,847,778	EURO €	747,780,013
Mooring System Maintenance	EURO €	29,160	EURO €	1,574,616
Transmission System O&M	EURO €	530,130	EURO €	28,627,025
Insurance/Device	EURO €	711,536	EURO €	38,422,939
Rent/Device	EURO €	646,851	EURO €	34,929,945
Utilities/Device	EURO €	344,362	EURO €	18,595,526
Undiscounted Lifetime OPEX	EURO €	22,577,948	EURO €	1,219,209,192
Total Lifetime Cost (Undiscounted)	EURO €	54,920,489	EURO €	2,965,706,427