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ABSTRACT

The study quantifies socio-economic benefits by the integration of wave energy in Greece, through resource examination, availability and deployment considerations. Greece has a large number of inhabited islands that mostly utilise conventional fuels for power generation, inclusion of wave energy will contribute both in terms of energy independence but also in job creation. The Greek region is often overlooked, due to its lower resources, but through proper converter selection energy benefits can be significant. Furthermore, milder resources offer opportunities for capital expenditure reductions, hence reducing cost of device and energy.

Scenarios consider technological maturity, legislation, and resource potential to quantify future cumulative installations that can be developed. If a wave energy converter (WEC) is selected properly, accounting for climate variability and persistence, currently several WEC designs can operate at capacity factors near at from 20%. Based on a resource and availability assessment, the learning rates from an incremental approach are more suitable and allow cost reductions. Job creation targets island regions where majority of exploitable resource is located and can provide up to 1400 direct jobs. Adaptation of wave energy by Greece has the potential to offer major technological, energy and employment benefits.

1. Introduction

Development of renewable energy (RE) has been at the forefront of European policies [1]. With the Conference of Parties (COP21) [2] concluded, even more ambitious targets have been set for a 2^oC reduction, thus inevitably renewable energies will play a key role for future energy systems. In order to achieve higher renewable energy contributions, maintain grid stability and reduce variability a multi-generation approach based on all indigenous resources is necessary.

Greece is located at the Eastern Mediterranean Basin and its electrical mix is heavily dependent on fossils (coal & oil) products [3]. In 2014 renewable energy contribution in electricity production was 21.9% and gross final energy consumption was 15.3% [4]. With majority of power production originating from lignite and coal plants, CO_2 and Green House Gas (GHG) emissions are high for the Greek region. The Hellenic electricity system can be divided into two categories: the interconnected (continental Greece) and autonomous (islands regions). Bulk of energy production which originates from fossil plants satisfies continental Greece, with islands relying from subsidized transfers of fossil fuels [5] resulting in a high Cost Of Energy (CoE), that in some cases reaches values of up to 270 Euro/MWh [6]. Large power facilities are owned by the Public Power Corporation (PPC), indicatively 2009 data recorded high levels of CO_2 emissions by the larger plants relying on lignite. Agios Dimitrios in Kozani emitted 12.9 MtCO_2, followed by Kardia and Ptolemais in Ptolemaida with 9.7 and 5.03 MtCO_2 respectively [7].

This heavily dominated fossil fuels power generation, led to the examination of the obligation compliance for the Greek power sector with the National Allocation Plan. Kaldellis et al. [8] evaluated the emissions and indicated that without proper actions for de-carbonisation targets, these obligatory compliances will not be met. Kaldellis et al., Zafirakis et al. [9,10] evaluated the social acceptance of renewable energy sources in Greece that are often cited as reasons for halting renewable development. They found that islands regions have higher societal acceptance rates and can benefit socially by increased renewable penetration.

Greece has been making steps to promote renewable energy development. Dominant renewable sources contributing to the gross energy production are wind, photovoltaic (solar& photovoltaic panel), followed by hydro (predominately large scale dams), geothermal, and localised biomass at smaller capacities [4]. Wind

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and photovoltaic have over (≈4 GW installed) [4,11,12], making them the highest contributors. However, with higher levels of renewable energy originating from limited number of technologies, several issues concerning grid stability, variability that significantly hinders continuous and uninterrupted power supply [13,14].

This study aims to contribute concrete evidence based arguments that support development and policy considerations regarding "hidden" opportunities of the emerging wave energy industry, with Greece taken as an indicative milder resource region. Since no policy considerations exist, the scenarios are developed based on examining energy production/performance, availability, and then applying learning curves to assess potential reduction in capital expenditure. With a wide range of costs, the solution selected is based on a long-term energy evaluation that allows to include climatic persistence and variations. Milder resources require less capital considerations on infrastructure, due to lower extreme conditions. The suggested potential learning rates offer valuable insight on the future unit cost of devices at milder waters and associated employment benefits. Hence the study, ties the socio-economic benefits with energy estimates and detail multi-year analysis.

Considering additional renewable generation in the energy policy of Greece, will accelerate de-carbonisation, increase energy independence, enhance security of supply, reduce energy imports and emissions. At the same time, significant local jobs can be created which can alleviate un-employment of skilled workforce and initiate de-centralised growth. With wave energy higher in Central Aegean and Southern islands, multiple benefits of energy to social development can be developed at the island regions.

2. Material and methods

Waves propagate and contain higher energy density than wind, with most energetic resources in Europe found at higher latitudes [15]. While, highly energetic environments are promising they also have increased survivability dangers associated with harsher environments and higher extreme events [16], such events can have hazardous effects on wave energy converters (WEC).

To date there are numerous devices (too many to mention), which are based on similar operational principles (i.e. pressure, oscillation, heave etc.) but have different power-take-off (PTO) and nominal capacities [17–19]. Asides operational characteristics a WEC has to be suitable for the location installed. This compatibility can be expressed by two factors, the annual energy production via the capacity factor and availability. Availability is expressed as the percentage of time for which the resource allows operation for the WEC, in this study availability is considered in terms of significant wave height (H_{sig}) [20].

These two indices allow to determine the suitability of a region based on its metocean characteristics [21], and to assess potential energy contributions in the long-term [22]. High energy sites are characterised by higher wave heights and larger swells, but have lower values of availability (depending always on converter range of operation). In addition, the probabilities for catastrophic extreme events are increased. To that end, suitable range operating WECs deployed at milder environment, can prove to be promising in energy production with lower risks [23,24].

2.1. Wave resource

To determine the wave resource and obtain robust estimates, long-term data are vital. When considering wave energy applications it is important to note that their applicability is limited by depth considerations, it is suggested that depths ≤ 150m are suitable for WEC farms [21,25].

Data from a 35 year long-term high resolution nearshore hindcast are used to assess metocean conditions. In the analysis, data from sub-mesh A are used (see Fig. 1), model information, calibration, validation and detailed energy analysis can be found in Lavidas et al. [24,26].

Wave power (P_{wave}) resource is characterised by significant wave height (H_{sig}) and energy wave period (T_e) for the summation of complex sea states over frequency (f) and direction domains (θ) (see Equation (1)), lower wave height areas encompass lower wave energy potential. Fig. 2 shows the mean P_{wave} over the Aegean Sea, most energetic regions are the Southern parts of Crete and Central Aegean islands.

$$P_x = \rho g \iint C_{gx} E(f,\theta) df d\theta \quad (1)$$

$$P_y = \rho g \iint C_{gy} E(f,\theta) df d\theta \quad (2)$$

$$P_{wave} = \sqrt{P_x^2 + P_y^2} \quad (3)$$

where $E(f,\theta)$ the energy density spectrum over an x (longitude) y (latitude) system. C_g are the components of absolute group velocities, water density (ρ), g gravitational acceleration. Total wave

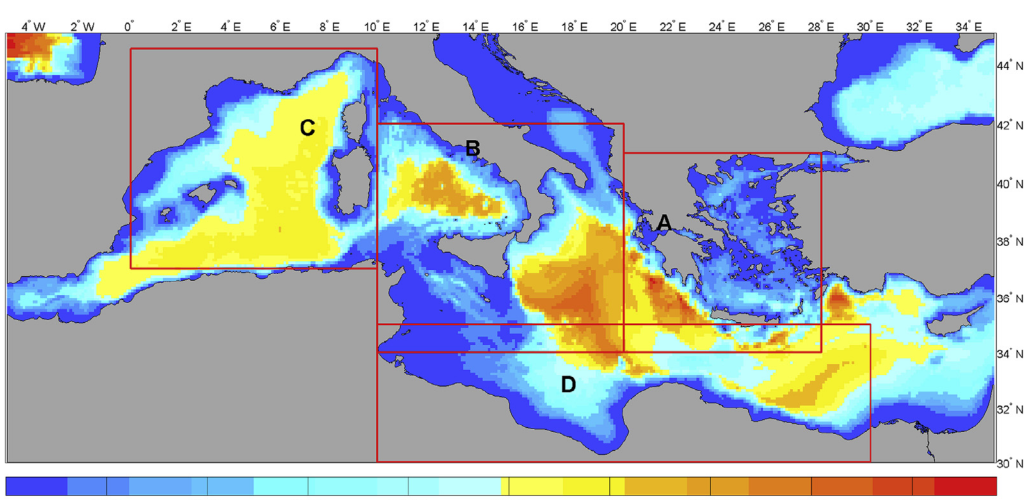

Fig. 1. Initial Coarse mesh with 0.1° resolution and subsequent meshes (colorbar depth in meters).

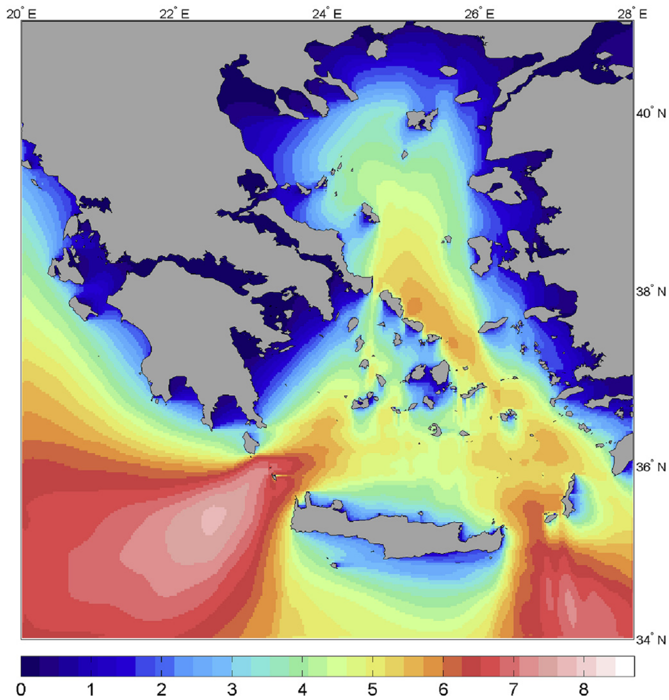

Fig. 2. Wave power P_{wave} in kW/m for 35 years at the Aegean Sea.

power is expressed in W/m or kW/m.

The seasonal Aegean mean resource over 35 years is presented in Fig. 3, with DJF = December-January-February, MAM = March-April-May, JJA = June-July-August, SON=September-October-November. Notable areas, for wave energy potential are the Crete, and Central Aegean. JJA has the lowest seasonal potential, with exception of South-East Aegean region where P_{wave} has highest values. From the extensive metocean and energy analysis discussed in Lavidas et al. [24]. joint distributions at the Aegean show that dominant wave environments are of low H_{sig} and high frequencies (low periods), populating ranges of H_{sig} from 1 to 3.5 m and 3–8 s for energy period T_e. Bivariate distributions suggest that most favourable WECs would be the ones that obtain highest rated capacity at mild to low wave heights. Though such converters have been developed [19], they can be further optimised based on long-term data increasing significantly energy production almost by 50% [23].

2.2. Renewable energy driven jobs

Developing renewable energy benefits diversification and energy security, but can also offer significant opportunities for employment and local growth. Jobs generated can be classified into two categories: direct and indirect, it must be underlined that there is great ambiguity concerning direct and indirect jobs, hence this analysis is predominately concerned with the potential of direct jobs [27,28]. Direct jobs are associated with production, installation,

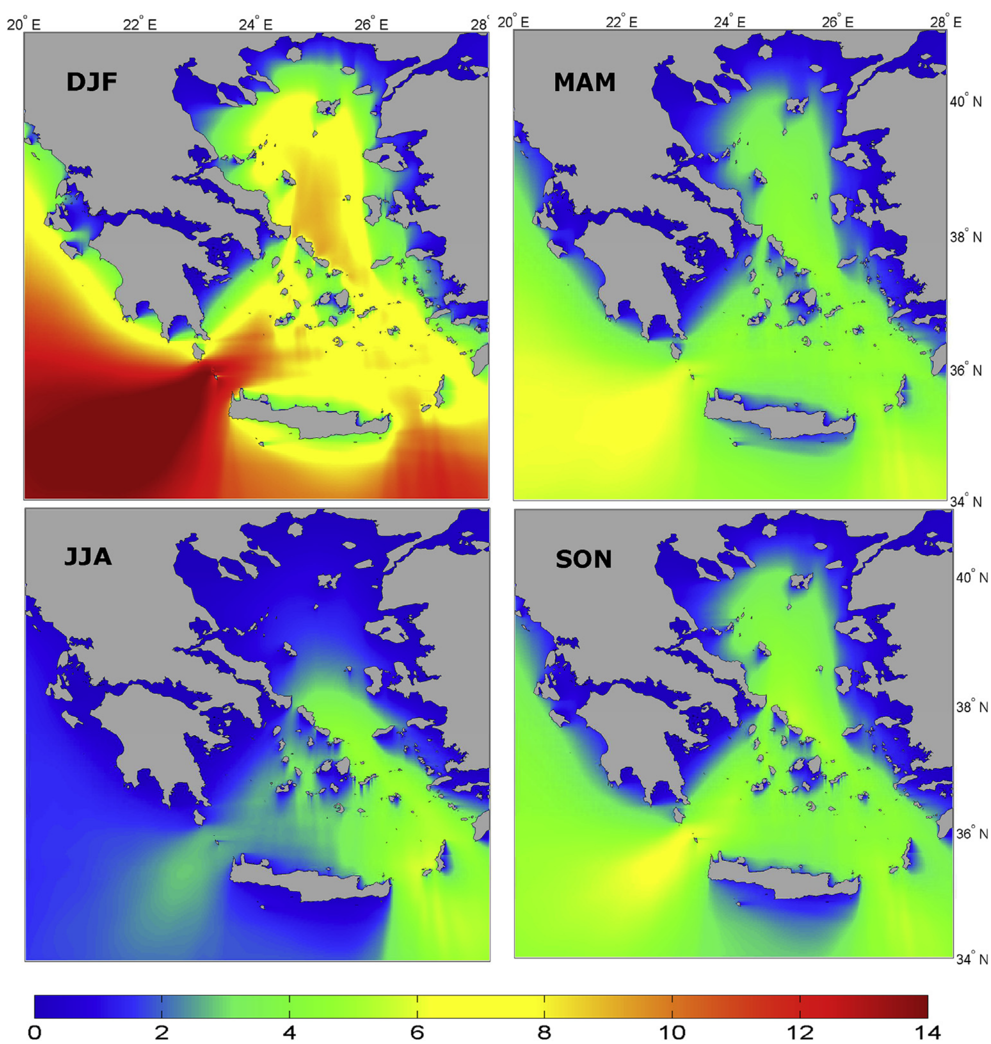

Fig. 3. Seasonal Distribution wave power P_{wave} in kW/m for 35 years at the Aegean Sea.

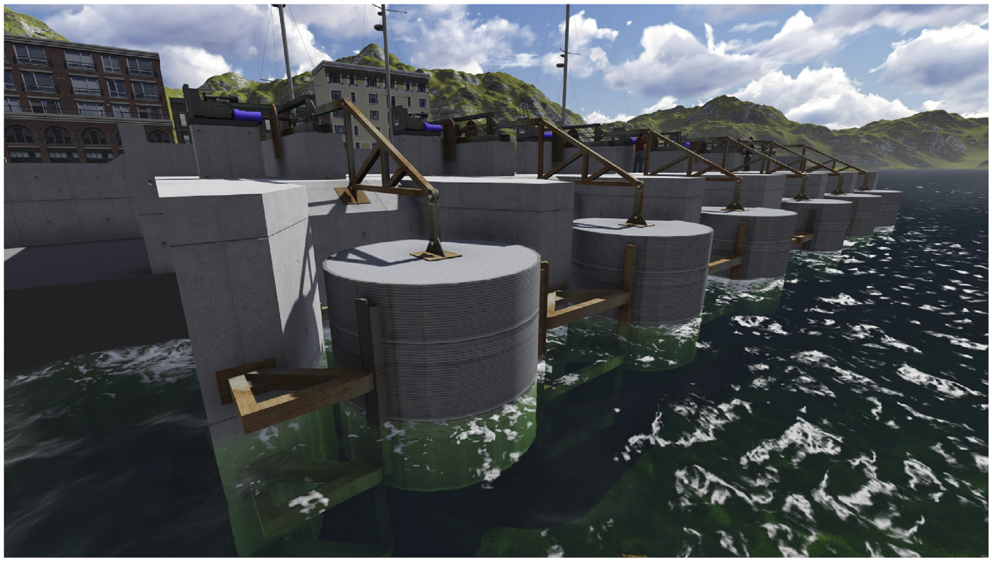

Fig. 4. WEC concept produced in Greece [42].

deployment, and maintenance of WEC farms. Indirect are jobs related with dependent activities to direct jobs, such as more localised employment to satisfy the emerging needs of direct employees [28,29]. It is important to note, that there is the lack of information concerning jobs attributed to the wave energy industry. Due to absence of decisive information, an analytical approach is used as the most favourable option. The analytical method has the benefits that its results can be used based on developed installation scenarios, but one of its limitations are results sensitivity on initial assumptions of installed capacity.

Amongst the factors that hinder WEC applications, is the uncertainty of their capital expenditure (CAPEX), which tends to depend on technology, and deployment depths. However, this also suggests that there are significant opportunities in the development of an industrial based approach by the Greek research and renewable sector. As an example Italy has decided to develop through appropriate schemes a wave energy converter industry to deploy suitable devices [30], and has increased the number of companies developing ocean energy solutions. Furthermore, WECs are modular converters that require construction/assembly and maintenance facilities near the region of installation, thus benefiting local job growth.

Previous studies indicate that wave industry jobs are similar to the numbers of direct jobs for offshore wind [27]. Thus, expected jobs are subjected to values same for the offshore wind industry and are based on final cumulative installed capacity. This scenario is considered due to the uncertainties that are associated with annual jobs as expressed in Dalton et al. [27]. who considered 10 jobs/MW for wave energy.

In order to estimate the cumulative effect on jobs from renewable energy, it is important to deploy a strategy to set targets [31]. To date the Greek legislative energy framework does not include WEC farms for its 2020 targets [32,33] nor even after that, indicating the low inclusion of emerging technologies by the State. No dedicated wave test facilities exist in Greece (such as EMEC), although WEC concepts have been deployed and tested by National Technical University of Athens (NTUA) which operates a marine test tank and a Naval Engineering research group. Also, the Department of Environment at the University of Aegean and the Hellenic Centre for Marine Research (HCMR) actively pursue and conduct some wave initiatives for hybrid wind-wave converters, wave energy, and investigate island applications, to name a few [34–36].

A Greek WEC concept has been developed by the private industrial sector (see Fig. 4) Wave Energy S.A and DAEDALUS informatics Ltd. Both companies were operational in the marine energy sector [35], for the latter its current status is unknown. Such developments indicate that technical knowledge exists, a fact that can assist in the development of a wave energy industry, which can be accelerated by several national and European funding schemes, such as FP7, HORIZON2020, NER300 etc. [37]. Several WEC farms have been deployed in test facilities around Europe such as SEM-REV, EMEC [34,38], while funds such as the NER300 have also dedicated grants for the development of WECs [39]. Most prominent example of funding for wave development are WestWave (5 MW) and SWELL (5.6 MW) wave farms, with ≈23.3 and ≈9.1 million Euro respectively, by the NER300 framework [38–41].

To initiate the scenario based approach it is important to determine a presumptive target and set the initial installed capacity. Development from 2016 to 2030 assumes initial install capacity for 2016 at 1 MW, similar to the target set by Italy that shares analogous wave resources [30,41]. Estimations for 2030 are based on learning rates (learning by doing) based on two schemes, an incremental and doubling of cumulative capacities. Specifically, for wave energy there are only a small number of studies on learning rates that suggest coefficients [43,44]. Learning rates allow projections for cumulative capacities and cost reductions by economies of scale. Projections can be based on doubling the cumulative capacity annually, or set a constant number of annual MW increase [43,45,46].

$$P_t = P_0 \cdot \left(\frac{x_t}{x_0}\right)^{-b} \tag{4}$$

$$LR = 1 - 2^{-b} \tag{5}$$

Learning rates are estimated with a single factor function to reduce the uncertainty of assumptions, see (Equation (4)). Where x_0 cumulative capacity at starting time, P_0 cost of unit produced at initial time, x_t is the cumulative capacity at time (t), P_t is cost of unit produced at time (t), and b is the learning parameter which is estimated by the learning rate (see Equation (5)).

3. Results

3.1. Availability

Another indicator that has to be determined is availability, this will assist in the identification of regions suitable for WEC operation, for which the resource corresponds to operation for a wave energy converter (WEC) expressed as a percentage of time. For a WEC, power is produced based on a specified combination of operational principles of significant wave height and wave period (varied). Like other renewable converters (i.e. wind), WECs have specific attributes concerning start of operation (H_{cut-in}) and end of operation (or survival mode) ($H_{sut-off}$).

Since our focus is on milder regions, and considering that most WECs suitable have ranges of operation from 0.5 to 3.5, in this study the availability is expressed as terms of two operational limits (low and high). A cut-in ($H_{sig_{cut-in}} = 0.5$ m), and a cut-off safety mode ($H_{sig_{cut-off}} = 4m$) are suitable and characterise majority of converters for lower resources. The database the study uses is from a hindcast of 35 years, that allows us to estimate the spatial distribution of availability (see Fig. 5) [26].

The thresholds as well as a deployment depth restriction ($\leq$ 150 m) have been applied to the hindcast database (see Fig. 5), in order to display the resource and deployment suitable regions. As in the case of mean wave power resource (see Fig. 2) Southern Greece and Central Aegean locations attain higher levels of availability. Cycladic islands coastlines have $\geq 60\%$, Crete has $\geq 45\%$, although Northern coasts have significant lower availability which corresponds to the lower wave resource. Exception is the Lhmnos island whose levels are $\approx 50\%$, indicating a potential Northern site with favourable extraction levels and lower return wave events. At South Central Greece, near Attika and Euboia Straits availability levels vary from $30-50\%$, encompassing also lower P_{wave}. At the Western side, the Ionian islands have lower levels from 15% to 40%, remaining coastal parts of Greece (continental, not islands) have similar levels of availability throughout $\leq 20\%$. It has to be noted, that in the case of Greece lower availability often corresponds to lower wave resource, as also indicated by P_{wave} levels. H_{sig} in Northern parts are often below the cut-in (lower) thresholds due to very low conditions thus reducing availability.

3.2. Power performance

Power by a WEC, as discussed in subsection 2.1, is usually done through estimating the bivariate distribution of metocean conditions and using a power matrix (PM). Additional information such as directionality, deployment guidelines (spacing), shading effects, and WEC interactions can add to a higher resolution energy analysis, they are often absent from available information. Concerning WEC interactions and array effects on converters, separate hydrodynamic studies are required.

Point absorbers and heave type converters, have the advantage that they can produce power from all in-coming directions. Guidelines [47] and previous studies have used metocean data to estimate potential energy production by a variety of WECs [22–24,48,49]. Power performance can be quantified by the amount of electricity produced (E_o) by utilising percentages of occurrence by bivariate distribution of wave height and periods, and combining it with power matrices. The final outcome can be

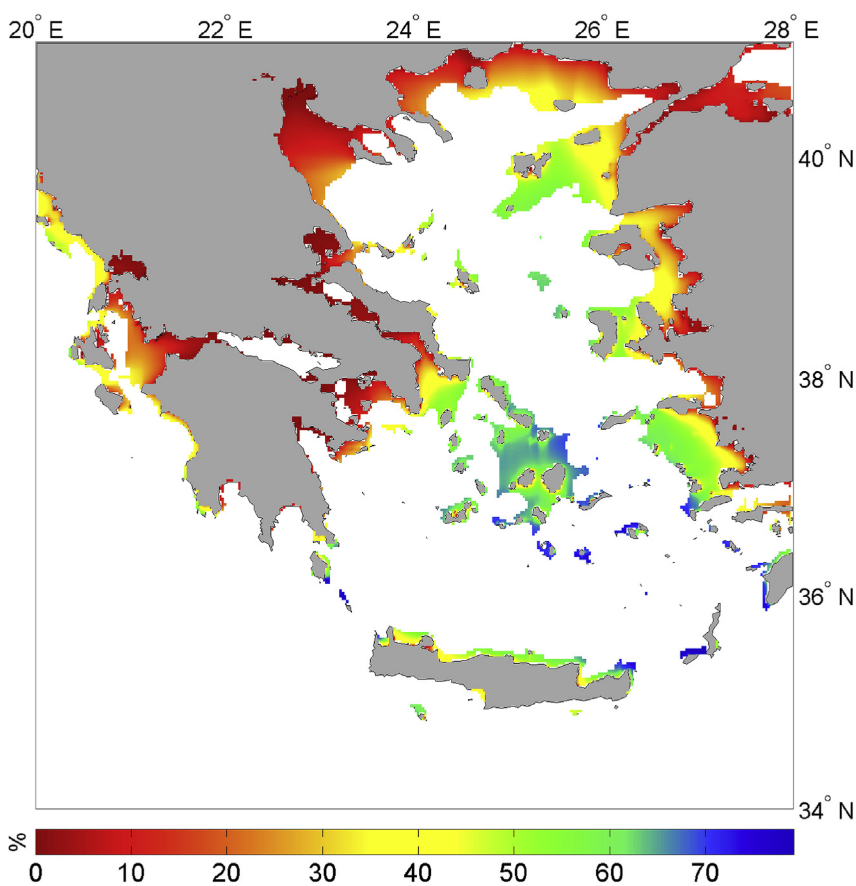

Fig. 5. Availability (%) depth restricted with $\leq$ 150 m and operational range from 0.5 m$\leq H_{sig} \leq$ 4 m.

expressed in the value of a capacity factor (CF) (See Equations (6) and (7)).

$$E_o = \frac{1}{100} \cdot \sum_{i=1}^{n_T} \sum_{i=1}^{n_{H_{sig}}} \cdot p_{i,j} \cdot PM_{i,j} \tag{6}$$

$$E_o = P_o \cdot \Delta T \cdot CF \tag{7}$$

The parameter $p_{i,j}$ represents the energy percentage corresponding to the bin assigned. $PM_{i,j}$ is the electrical expected output by the same bin as state by the power matrix. Column is denoted j, and the row as i. ΔT (i.e. 8760 h/year for 1 h) is the measurement time and P_o the rated capacity of the WEC.

For Greece most suitable WECs achieved a performance (capacity factor) of 10–17% in Crete, and 14–20% in the Central Aegean, for more detail information the reader is diverted to [24]. The process followed estimation of CF based on Equations (6) and (7), and has applied an additional criterion which depends on depth. Majority of WECs are advised to be installed at bottom depths ≤ 150 m. For this reason areas for which the depth criterion is not satisfied are excluded.

With P_{wave} lower than higher latitudes this also indicated smaller extreme levels and potentially harsher events [50,51]. Interesting regions in the Aegean, are the ones that have "higher" P_{wave} and lower covariance, tending to be more consistent throughout the years [24,26,52]. This can contribute to reduction of capital expenditure due to lower extremes, and increase the reliability for operation. It is important though to select a WEC that correspond well to regional metocean conditions, striking a balance between costs and extracted power.

Suitable wave energy locations in Greece, are Central Aegean and Crete. At those areas the average capacity factors are from 10 to 20%, see Fig. 6, which are comparable with current levels of photovoltaic. In addition, proof of concept and further scaling to resource, can add to optimised energy production benefits. Optimised WECs can also obtain increased availability, something that is not possible in the case of solar resource which has a specific time constrain.

3.3. Economic benefits of wave energy

3.3.1. Learning rates for WECs in the Aegean

Currently the Greek government has no allocated targets for wave energy [33], due to this fact as base case the Italian framework is considered; that proposes wave energy installed capacity to reach 3 MW by 2020 [30]. A similar low capacity is examined with two scenarios for wave energy implementation. Starting year for all scenarios is 2016 and final period is 2030. It has to be noted that capital expenditure (CAPEX) for WECs is highly volatile, dependent on technology selected, and considerations on metocean conditions of location to be installed [53,54]. For this reason three representative CAPEX values are used starting from 3 million € incrementally increased by 1 million until 5 million € is reached. Finally, the learning parameter necessary for estimating learning rates is set at 0.15 as found in Refs. [43,44] which suggest a similar "learning-by-doing" experience for novel technologies.

For 2016 the starting installed capacity is set at 1 MW, the incremental scenario considers additional 2 MW of wave farms added each year, while the most optimistic follows the double of cumulative capacity. Table 1 presents the assumptions considered for all scenarios.

When annual doubling occurs (scenario Double), the 2030 installed capacity reaches 16384 MW, while when the incremental approach is examined (scenario Incr) is 30 MW. Correspondingly unit costs (million €/MW) have different values, with more favourable the Double scenarios. Specifically, when annual doubling capacity is examined the Low scenario reduces in 2030 the unit cost at ≈500 k€/MW, Medium ≈770 k€/MW, and High ≈ 970 k€/MW, in this option reduction of cost is "smoother" (see Fig. 7). For the Incremental scenarios, costs do not achieve similar reductions. It can be observed that a "sharp" decline occurs in 2017 due to economies of scale and faster cumulative deployments for which afterwards costs reduce at lower rates. Unit cost in 2030 are ≈1.6, ≈2.1, and ≈2.7 million €/MW for Low, Medium and High

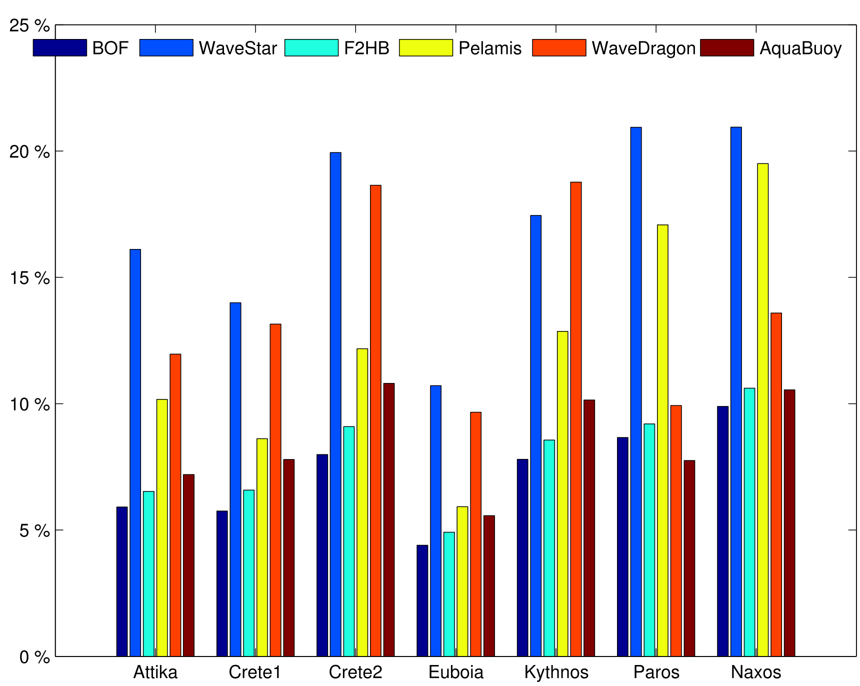

Fig. 6. Indicative performance of various converters around the Greek region [24].

Table 1
Scenario inputs.

	Low	Medium	High
Double			
CAPEX	3 m€	4 m€	5 m€
Initial capacity (MW)	1	1	1
Learning parameter	0.15	0.15	0.15
Incr			
	Low	Medium	High
CAPEX	3 m€	4 m€	5 m€
Initial capacity (MW)	1	1	1
Incremental capacity (MW)	2	2	2
Learning parameter	0.15	0.15	0.15

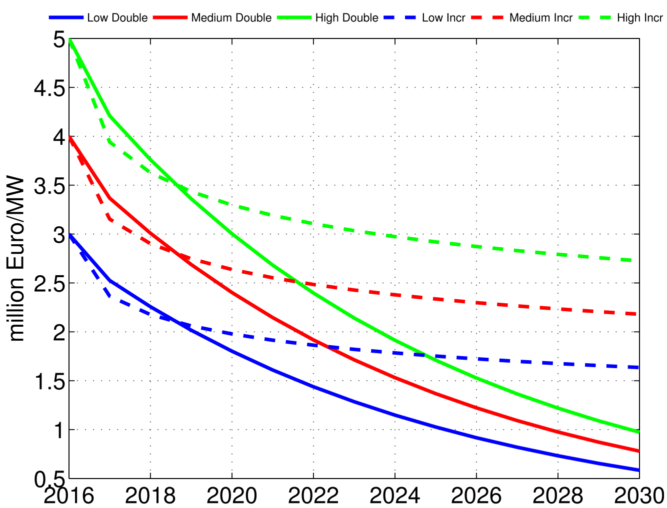

Fig. 7. Unit cost per MW after application of extrapolated learning rates.

respectively.

Considering the level of WEC maturity, wave power resource, potential for installations, deployment depths and availability, the most realistic assumption would be an incremental approach to learning rates for WECs in the Aegean. Considering the deployment restrictions as well, one has to be cautious when using learning rates and must always have a critical approach to the parametrisation and selection of viable realistic scenarios. Thus, building upon the incremental evaluation, same costs and initial assumption are retained, although the annual installation steps are subjected to incremental increases from 1 to 10 MW annually, with intervals of 0.5 MW. Providing a multi-evaluation of different annual energy policies that may be used to affect wave energy developments.

Sensitivity analysis of increments shows different levels of final installed capacity by 2030 (see panel(a) Fig. 8). With an annual increase of 1.5 MW in installation 2030 cumulative capacity reaches 22 MW, while with a 10 MW annual increase it reaches ≈141 MW. These estimation also allow to extrapolate potential reductions in unit cost, from a learning by doing approach (see panel (b-d) Fig. 8). In the Low cost scenario and highest decrease of CAPEX/MW is ≈1.2 m€, for Medium scenario most optimistic reduction see final unit costs at ≈1.6 m€, and the most expensive High option has best reduction set at ≈2.1 m€.

Considering that WEC technologies are in their early commercial levels, unit costs show that they can achieve economies of scale even at milder environments. These considerations can assist in diversification of the energy mix by offering a feasible solution. Ongoing activities in research, development, and optimisation of WECs for milder environment [23] are promising, and indicate further achievable reductions in terms of capital expenditure. Resulting in an alternative form of renewable energy that can be considered, as P_{wave} has similar levels with other European region which actively pursue the implementation of wave energy into their energy mix.

3.3.2. *Employment benefits-opportunities*

While energy generation and cost of energy assist in disseminating the potential of each technology. Another, indirect factor that contributes to policies is the economic and social growth that a sector can develop. As mentioned, majority of devices has been developed by countries with energetic environments. While Greece, seems an unlikely candidate to develop such a technology, fact of the matter is that there is ample research and development experience in the wave energy sector. Thus, in order to enhance the potential positive benefits, the job growth from wave energy can also act as a positive factor to enhance and promote policy considerations.

Like any other renewable energy, local and national job opportunities are significant from the development of wave energy as an active industry. Due to similarities and structural components, offshore technologies are often used to estimate direct jobs. In addition to job creation, the sectoral impact is also addressed by the use of a breakdown employment multiplier [31]. These multipliers breakdown the sectoral distribution of jobs that correspond to the WEC industry. To avoid ambiguity from annual estimates, the final 2030 cumulative targets are estimated and the multiplier are used on the installed capacities reached by the incremental scenario. This allows for a direct measure of potential job opportunities from the WEC industry development.

The author believes that most viable scenario is the incremental, considering current legislative energy policy in Greece and resource availability. Evaluation is limited to the estimation of potential jobs by a sensitivity analysis of aggregate final installations reached by 2030, as indicated from subsection 3.3.1. Considering 10 jobs created for every MW of wave energy installation [27], the breakdown of each sector contributing is seen in Fig. 9.

Even with the lowest annual cumulative increment, the direct jobs that can be created are 150. As the potential annual installations increment increases jobs gained at the end can reach up to 1410 positions. Majority of opportunities are within the electromechanical, construction and installation section of the wave energy farm, which constitute over 50% of potential employment opportunities (see Fig. 10). Obviously if we consider the highly optimistic learning rate case, i.e. Doubling cumulative annually. The

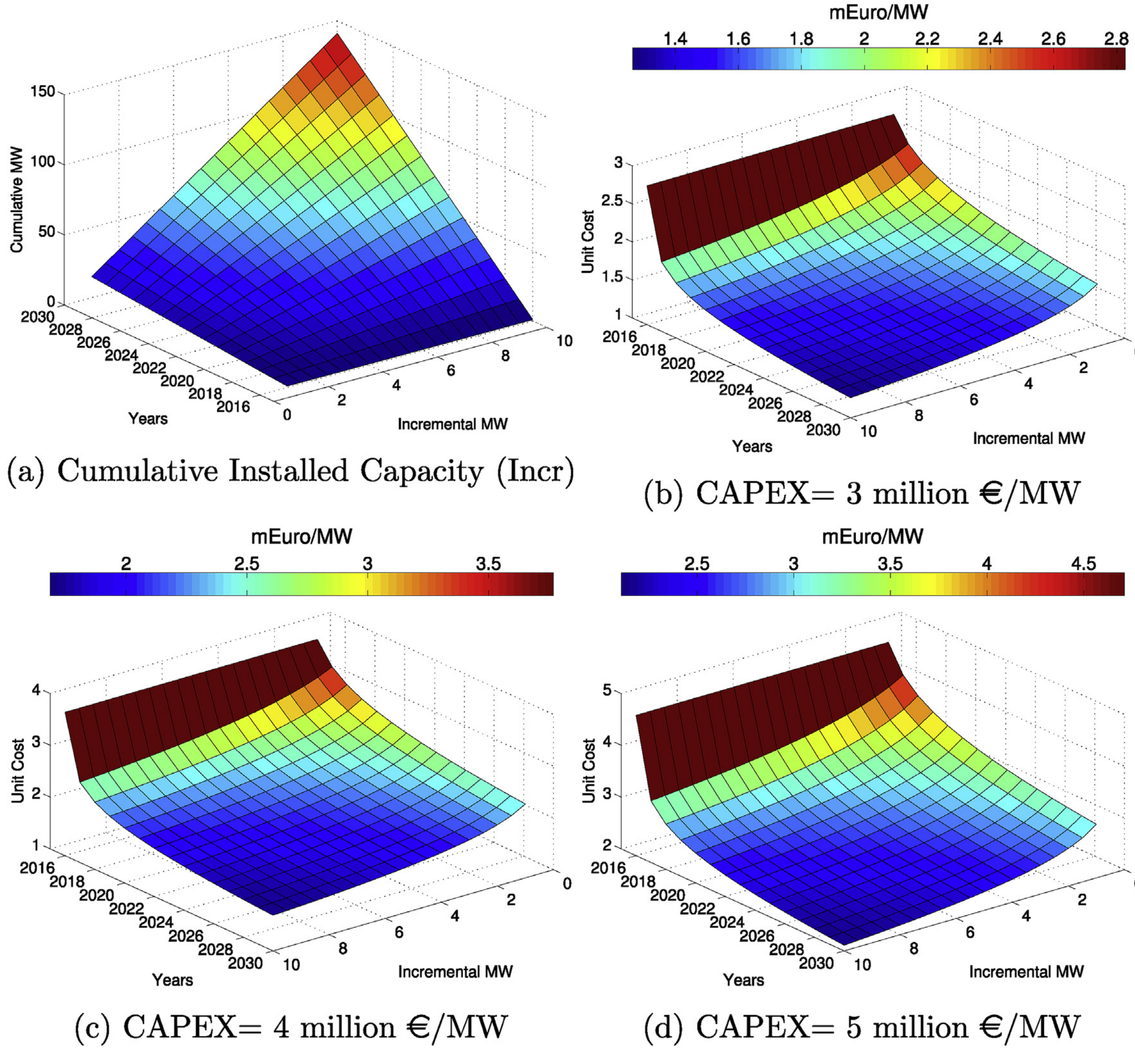

Fig. 8. Incremental sensitivity scenarios, panel (a) Cumulative Installations, panels (b–d) Unit Costs for Low, Medium, High Scenarios.

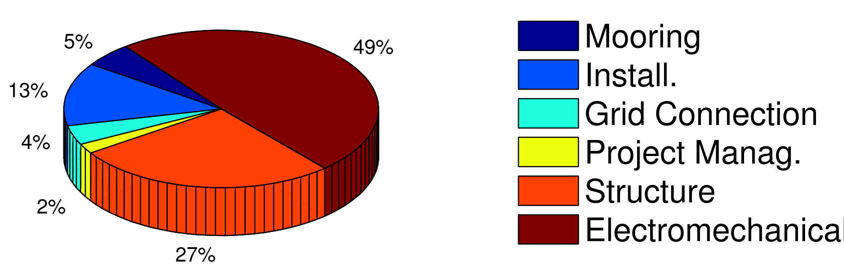

Fig. 9. Employment multiplier effects.

number of jobs created increases significantly, though as presented current considerations do not suggest this option as viable.

Another not so obvious advantage in terms of job creation is the locality of employment. The analysis has considered indicative values of high energetic P_{wave} areas in the Aegean. As underlined, Cyclades and Central Aegean pose interesting regions for which wave energy is an intriguing proposal. Thus, aside de-carbonisation of local autonomous heavily dependent on fossil fuels production, direct jobs may benefit the island population. Especially, in the case of operation and maintenance it can provide opportunities for skilled staff located at the islands in order to monitor and perform necessary operations.

Finally, it is expected that direct jobs also contribute to increases in indirect employment, for example development of local hospitality sector to accommodate new industries. Though, these kind of opportunities are hard to quantify even in the case of established sectors.

4. Discussion

Benefits of integrating renewable energy source are widely known. Multi generating RE options can strengthen and offer

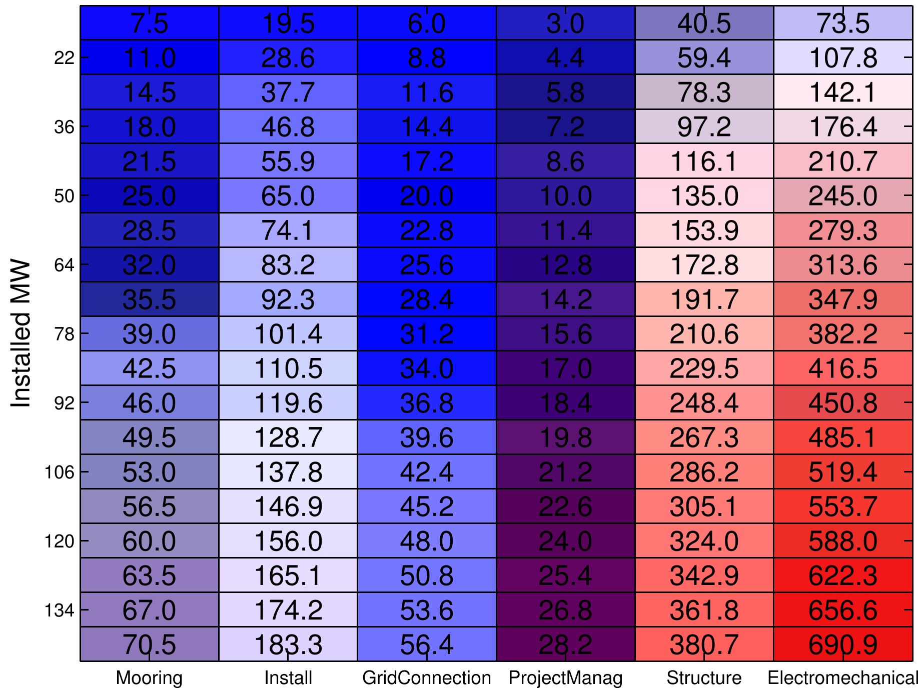

Fig. 10. Jobs/MW created in 2030 final cumulative.

diversification to the energy policies of a country [14,55]. In order to enhance such benefits all available resource have to explored with their energy, and additional benefits quantified.

In the case of offshore energies in the Aegean, most prominent is consideration of wind energy although metocean data are also important for platform deployments. While, the maturity of offshore wind is based on technical knowledge gained by onshore installations, it still has variability as any other resource. It is suggested that RE multi-generation reduces variable RE production and decreases costs [56]. So far the Greek electrical system has benefited immensely by the introduction of photovoltaic, wind (onshore), and local biomass production. Though, as years progress and RE penetration increases, grid stability issues arise. Photovoltaic generation has a distinct profile with production only over daytime.

Wave energy production, as in the case of wind is mostly independent of the temporal domain (i.e. it has the potential of production hours throughout the day) unlike solar. Wave resources are abundant in the Greek territory, multiple islands can benefit from additional energy production and have a positive impact on diversification of energy policy.

The emerging wave energy industry can provide significant energy and socio-economic opportunities in Greece. Building upon research experiences and the growing body of studies for the Aegean, WECs can contribute in development of the Greek renewable industrial sector. Initial proposed installation targets for Greek wave energy are bound to be smaller, due to resource and applicability considerations in this study. With proper determination of resource, metocean characteristics, selection of site and device, it can provide up to ≈ 1.7 GWh/1 MW_{WEC}/year. Even in the conservative scenario, with 1 MW incremental development, final 2030 energy contribution by WECs can amount $\approx 26GWh/15$ MW_{WEC}/year. When considering the highest annual increment, i.e. 10 MW/year, energy contributions can amount $\approx 247GWh$ from final cumulative installations of 141 MW.

Asides obvious energy security, security of supply, reduction of GHG, and CO_2 emissions, a strong socio-economic benefit is gained. With the modest incremental scenario, direct jobs related to wave energy installations can amount to >700 jobs. Such jobs benefit the highly skilled population, especially in island areas, where opportunities for energy professionals are limited.

Identification of renewable energy source opportunities are of high significance to be included in any long-term energy planning policy. Especially for Greece whose energy system contains a high number of de-centralised (autonomous), fossil dependent power production in its islands. With high solar, wind, and interesting wave resources throughout the central Aegean and large islands (such as Crete), wave energy can contribute to the increasing renewables portfolio. At the same time it will re-ignite the industrial opportunities for development of WEC which can be of interest to other countries that are exposed to similar resource.

5. Conclusions

In this study benefits by WEC application were examined. The analysis was not limited to energy and resource quantification. The milder resource offers high levels of availability for wave energy production. Central Aegean and Southern regions have the highest levels in Greek maritime regions making them more attractive. At the same time the high number of autonomous islands, that are heavily dependent on fossil fuels increase the attractiveness for additional RE production to ensure energy diversification. Proper selection of a WEC based on dominant metocean characteristics, can provide capacity factors similar to other renewable technologies. Asides, temporal RE production overlaps, further diversification of the energy mix increases the positive synergies for renewable energies. Although, Greece has not considered wave energy in its strategic energy plan.

With lower resources extreme events are reduced and survivability is enhanced, something that is often overlooked. This lead to increased operation, lower infrastructure and maintenance costs. Hence, potential applications over a long-time frame can yield significant cost reductions in capital expenditure. At the same time it will provide a significant technical sector, which can be used for the development of renewable energy industry in Greece. Including WEC farms in the energy mix creates significant opportunities in job creation locally and centrally.

Through application of learning rates the potential cumulative installed capacity that can be reached in 2030 by wave farms was also estimated. An incremental annual increase was deemed favourable, in contrast with the most commonly used double cumulative theory. This was more appropriate as considerations of current framework, resource and available locations were discussed. Learning rates with multiple increments, display that 2030 cumulative installations of wave energy farms can be from 25MW and reach up to 141 MW. These in turn also contribute to significant reductions of Unit Cost, as indicated from a "learning by doing" approach. This reduces the cost per MW and the Cost of Energy by WECs for the Aegean region, leading to a lower levelised cost of energy.

Another important factor examined is the potential job and sector creation in Greece. With early state industries, such as wave energy, there are significant opportunities that can be gained by building upon research and technical knowledge of the wave energy sector. Adaptation of wave energy in the Greek electricity mix can contribute direct jobs, which become ever more important as WEC farms, are favourable in non-centralised electrical grids. Development of wave energy farms can provide a spur on localised job growth and enhance regional development, as past experiences with renewable energy project have done.

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