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The economics of wave energy: A review

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ABSTRACT

Wave energy is arguably one of the most promising renewables. Less developed at present than other renewables, the existing models to estimate the costs of a wave energy project are often oversimplified, and the resulting scatter in the economic assessments weighs on the confidence of potential investors and constitutes therefore an impediment to the development of wave energy. Indeed, understanding the costs of wave energy is one of the main fields of research in marine renewable energy. In this context, the main objective of this paper is to review all the factors that must be considered in an economic analysis of wave energy, including a number of elements that are usually overlooked. In the process we characterise the direct and indirect costs of a wave farm – preliminary costs, construction, operation and maintenance and decommissioning cost – as well as its prospective incomes. For each of them a reference value is presented, together with a generic formula for its calculation. Moreover, the levelised cost, i.e., the production cost of an energy unit (1 kW h), is compared between various energy sources, and on these grounds conclusions on the profitability and competitiveness of wave energy are drawn. In sum, this work reviews the state of the art and sets the basis for a thorough economic analysis of wave energy.

Contents

1. Introduction

In 2007 the European Union (EU) undertook to transform Europe into a highly energy-efficient and low-GHG economy, committing to reduce 20% of CO_2 emissions, to reduce 20% of energy consumption and to achieve the target of a 20% of the total energy consumption of the EU made up of renewable energy (Directive 2099/28/EC). The main focus of this policy has been on wind and solar energy. In order to reach the desired percentages, however, it is necessary to develop other forms of renewable energy less developed at present but with high potential [1,2], such as marine energy—carried by ocean waves, tides, salinity, and ocean temperature differences. Among these different alternatives, this paper is focused in wave energy [3,4] which, although it is in an initial stage of development, presents extensive possibilities for the future thanks to its enormous potential for electricity

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Nomenclature

$C_{elect.inst.}$	cost of the electrical installation (€)
$C_{initial}$	initial cost (€)
$C_{mooring}$	cost of the mooring system and its installation (€)
$C_{subest.}$	cost of the electrical substation (€)
C_t	the stream of (real) future costs
$C_{und.cab.}$	underwater cable cost per unit of length (€/m)
$C_{subt.cab.}$	underground cable cost per unit of length (€/m)
C_{WEC}	cost of one converter and its installation (€/WEC)
CALM	catenary anchor leg mooring
CAPEX	CAPital EXpenditure (€)
CCGT	combined cycle gas turbine
CCS	carbon capture and storage
CER	European waste catalogue
d	diameter of the chain (mm)
ETS	European trading scheme
EUA	dealing of carbon credits among companies
f_e	efficiency of electrical energy conversion
f_m	mechanical efficiency of conversion and the hydrodynamic power of a farm
f_t	efficiency of electrical energy transmission
FIT	feed-in-tariff (€/MW h)
GDP	gross domestic product
GHG	greenhouse gas
h	water depth (m)
HVDC	high voltage direct current
IGCC	integrated gasification combined cycle
K	a constant with value 0.02 kg/(m mm^2) for studless chain and 0.0219 kg/(m mm^2) for stud-link chain
L	length of the chain (m)
LC_D	levelised costs measure under the discounting method (€/MW h)
$L_{offshore}$	meters of underwater electric cable (m)
$L_{onshore}$	meters of underground cable until the electrical network (m)
N	number of converters
O_t	stream of (real) future (electrical) outputs
O&M	operation and maintenance
OPEX	operational expenditure
OWC	oscillating water column
P_{Chain}	weight of the chain (N)
P_f	final power of the whole installation (W)
P_h	hydrodynamic power (W)
P-Val	present value. This factor can be referred to costs or power output (€, MW h)
PV	photo voltaic
PWR	pressurized water reactor
r	discount rate (interest rate used to bring future values into the present)
t	a point of time (s)
T	service life of the wave farm (s)
WEC	wave energy converter

production [5–19], in the same way than tidal or offshore wind energy [20–29]. In fact, the global wave energy resource is estimated at 17 TW h/year [30], with the largest values of average wave power in the mid-latitudes (between 30° and 60°) (Fig. 1).

Nevertheless, the main barriers in the development of marine energies are: (i) the early stage of development of the technologies [32–40], (ii) the uncertainties regarding the coastal and marine impacts of wave farms [41–51], and (iii) the fact that they have been considered uneconomical [52]. In this sense, the importance of the economic evaluation of wave energy can hardly be overstated—indeed, economic viability is a sine qua non condition for the development of this novel renewable; it involves a detailed evaluation of costs and private profits (income) associated with investment on these technologies. This way, the vast majority of studies about this field [22,53–58] are based in this last point; indeed, it is possible to find studies on wave energy profitability at specific locations according with the current charging system. For example, [56] or [57] are focused on the Irish economy, [53] on the UK and [54] analyses the effects on the Scottish economy of installing 3 GW of wave energy: effect on GDP (Gross Domestic Product), creation of new jobs, and so on. However, since wave energy technology is in an initial stage of research [59] and it is difficult to estimate the costs and performance of the device and the rest of the installation, the most part of current economic studies are oversimplified, and this could create insecurity in investors. In this context, this paper establishes the different costs incurred in a wave energy farm, their expected values and future evolution. With this information, the levelised cost (€/MW h) is

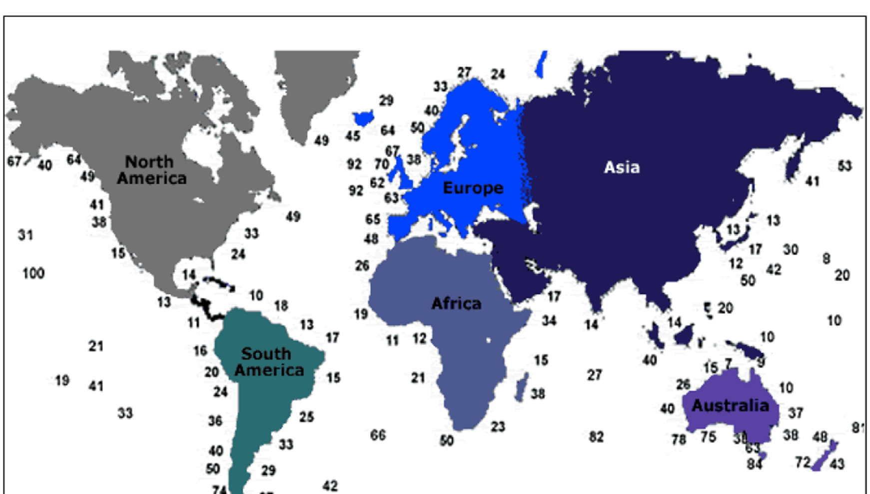

Fig. 1. Global distribution of the wave energy resource (average wave power in kW m^{-1}) [31].