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Assessing the impacts of technology improvements on the deployment of marine energy in Europe with an energy system perspective[☆]

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ABSTRACT

Marine energy could play a significant role in the long-term energy system in Europe, and substantial resources have been allocated to research and development in this field. The main objective of this paper is to assess how technology improvements affect the deployment of marine energy in the EU. To do so the linear optimization, technology-rich model JRC-EU-TIMES is used. A sensitivity analysis is performed, varying technology costs and conversion efficiency under two different carbon-emissions paths for Europe: a current policy initiative scenario and a scenario with long-term overall CO_2 emission reductions. We conclude that, within the range of technology improvements explored, wave energy does not become cost-competitive in the modelled horizon. For tidal energy, although costs are important in determining its deployment, conversion efficiency also plays a crucial role. Ensuring the cost-effectiveness of tidal power by 2030 requires efficiency improvements by 40% above current expectations or cost reductions by 50%. High carbon prices are also needed to improve the competitiveness of marine energy. Finally, our results indicate that investing 0.1–1.1 $BEuro_{2010}$ per year in R&D and innovation for the marine power industry could be cost-effective in the EU, if leading to cost reduction or efficiency improvements in the range explored.

1. Introduction

Climate change and energy policies are strongly interlinked: energy-related greenhouse gases (GHG) emissions in the EU27[2] accounted for almost 80% of the total in 2011 ([1] and [2]). Moreover, 40% of 2010 GHG emissions could be attributed to energy industries alone (electricity and refineries mainly) [3]. To address the challenge, the EU is defining a new set of energy policies that will provide additional impetus to the decarbonisation of the power system. In Refs. [4], the European Commission addresses energy and climate change policies in concert, with a view to reaching a reduction of GHG emissions of 40% in 2030 with respect to 1990 levels. It recognises that the rapid development of renewable energy sources poses new challenges to the energy system, notably the integration of decentralised and variable production in the electricity system. The Communication also highlights the need to ramp up research and development (R&D) and innovation investments beyond 2020, while at the same time setting priorities to accelerate cost reduction and market uptake of key low-carbon technologies.

The power sector has a critical role to play in ensuring meeting short and long-term energy and climate objectives in the EU. Marine energy encompasses a group of low-carbon technologies that could play a significant role in the transition of the power sector in Europe, contributing to energy security as well as to the reduction in emissions of greenhouse gases. As indicated in Refs. [5], the sector could also generate 40,000 jobs by 2035. It is thus important to better understand how key parameters affect investment decisions in marine technologies in an energy system perspective.

☆ The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

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The main objective of this paper is therefore to assess, within a systematic and coherent energy system framework, how technology cost and conversion efficiency affect the competiveness and deployment of marine energy technologies in the EU. Such analysis is intended to provide insights on priorities for R&D and innovation to accelerate the market readiness of marine technologies. To the best of our knowledge, no comprehensive assessment has yet been carried out exploring the role of marine energy for the medium and long term decarbonisation of the European energy system within an energy system perspective, though country-level studies adopting similar approaches do exist, for instance, for the United Kingdom [6]. A similar approach was used to determine the potential contribution of wave energy in the US energy system by using the NREL Re-EDS model as shown in Refs. [7], whilst the EIA [8] considered the potential contribution of wave and tidal technologies at global level, albeit showing limited contributions up to 2040.

The remainder of the paper is organised as follows. Section 2 briefly summarises the state of play of marine energy in the EU28,[3] and highlights the expected developments in the medium and long term. Section 3 outlines the key elements of the JRC-EU-TIMES model, describes the policy assumptions underlying the two decarbonisation pathways explored in the paper, and summarises the sensitivity analyses performed. Section 4 presents the main results, focussing on the impacts of marine technologies improvements on its deployment. Section 5 concludes the paper.

2. Marine energy: state of play

Wave and tidal energy technologies are the two forms of marine energy expected to provide significant contribution to the EU energy system in the next few decades [9]. Several European countries, in particular those located on the Atlantic Arc of the continent, benefit from vast resources and have a significant potential for the development of marine energy technologies. The United Kingdom, for example, has an estimated tidal energy economic potential of 18TWh/year, while 50TWh/year could become economically viable for wave ([10] and [11]). According to Ocean Energy Europe, wave and tidal technologies could reach up to 100 GW of installed capacity by 2050, with over 260TWh delivered to the grid [12]. However, in the past few years, 2020 projections have been significantly reduced from 3 GW of expected capacity [13,14] to 240 MW [15], with forecasts for the UK alone reducing from 1.95 GW [16] to 140 MW [17].

Despite reduced targets, Europe maintains a leadership position in the development of the marine energy sector and many European countries are at the forefront of innovation [18]. The United Kingdom, Ireland, France and Norway present hubs for both technology development and market mechanisms to facilitate the deployment of full-scale prototypes and devices, such as MEAD in the UK,[4] and the newly launched Offshore Energy Renewable Energy plan in Ireland [19].

A number of technologies are moving from prototype demonstration towards pre-commercial pilot arrays in order to prove reliability, survivability and affordability; however the high costs associated with ocean energy and technological fragmentation are currently hindering both access to finance and market uptake. As shown in Fig. 1, tidal technologies appear closer to commercialisation presenting a greater design convergence, having proved operation generating significant electricity supplied to the grid and with a series of array demonstration projects in the pipeline. On the other hand, wave technologies have yet to show the same level of reliability, and the current lack of design consensus is delaying the engagement with the manufacturing and supply chain to provide substantial cost-reduction and favour their market uptake [7].

While the performance of marine energy technologies is expected to improve steadily over time, their market-readiness and competitiveness will depend on whether such improvements lead to sufficient cost reductions and/or efficiency gains. The currently observed trends show the development of the sector to be below initial expectations. According to a recent report by the Strategic Initiative for Ocean Energy [20], cost of energy predictions for marine energy indicate that tidal technology could be competitive with other renewable energy sources (RES) when a cumulative capacity of 2.5–5 GW is reached, whilst wave requires 5–10 GW to ensure competiveness. There is therefore the need for stepping up efforts in innovation, R&D and demonstration to accelerate learning and cost reduction, thus enabling marine energy to play its role in the medium and long-term decarbonisation of Europe. Consolidating Europe's position as the leading centre for innovation is therefore critical.

3. Methodology and approach

3.1. The JRC-EU-TIMES model

This section briefly describes the key characteristics of the JRC-EU-TIMES model, its main inputs and outputs. Special attention is devoted to how the modelling framework addresses marine energy technologies. An extensive description of the model can be found in Ref. [21].

The JRC-EU-TIMES model is a linear optimization, bottom-up, technology-rich model generated with the TIMES model generator from ETSAP (Energy Technology Systems Analysis Program), an implementing agreement of the International Energy Agency ([22], [23]). It represents the energy system of the EU28 plus Switzerland, Iceland and Norway (EU28+) from 2005 to 2050, with each country constituting one region of the model. Each year is divided in 12 time-slices that represent an average of day, night and peak demand for every season of the year.

The equilibrium is driven by the maximization (via linear programming) of welfare, defined as the discounted present value of the sum of producers and consumers surplus. The maximization is subject to several constraints, including: upper limits on the supply of primary resources; constraints governing technology deployment; balance constraints for energy and emissions; and the satisfaction of energy services demands in the modelled sectors of the economy (primary energy supply; electricity generation; industry; residential; commercial; agriculture; and transport).

The most relevant model outputs are: the annual stock and activity of energy supply and demand technologies for each region and period; the associated energy and material flows, including emissions to air and fuel consumption for each energy carrier; operation and maintenance costs, investment costs, energy and materials commodities prices.

The main drivers and exogenous inputs are summarised in Fig. 2.

3.1.1. Energy services and materials demand

The materials and energy demand projections for each country are differentiated by economic sector and end-use energy service, using as a start point historical 2005 data and macroeconomic projections from the GEM-E3 model [25] as detailed in Refs. [21], and in line with the values considered in the EU Energy Roadmap 2050 reference scenario [26]. From 2005 till 2050 the exogenous

[3] As in,[2] plus Croatia.

[4] https://www.gov.uk/innovation-funding-for-low-carbon-technologies-opportunities-for-bidders#the-marine-energy-array-demonstrator-mead-scheme.