BARCELONA AND THE ENERGIES OF THE SEA

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1. MARINE RENEWABLE ENERGY: POTENTIALS AND IMPACTS

In this section the different marine energy technologies and their corresponding evaluated potentials (mainly theoretical) are explained. Then the impacts of the marine energy infrastructures are exposed with special emphasis on floating offshore wind technologies.

Numerous studies concur on the vast potential of global marine energy resources, which surpass the world's annual electricity demand, which stood at 98.8 EJ/yr (27,447.4 TWh/yr) in 2021[1].While the theoretical capacity is apparent, the actual energy extraction estimates remain uncertain, and the effectiveness of various technologies varies substantially depending on the energy source[2].

Currently, only a small fraction of this resource is being harnessed, with 30 operational ocean energy facilities worldwide. These include fourteen for tidal energy, fourteen for wave energy, one for salinity gradient (SGE), and a solitary facility for thermal gradient (OTEC), as detailed in the Ocean Energy Systems 2022 Annual Report[3]. Notably, there are presently no operational ocean current platforms. Asia, with 261 MW, and Europe, with 253 MW, contribute nearly equally to the global installed capacity (based on 2022 data from IEA-OES, 2023). This total capacity falls within the range of 517 MW[4] to 524 MW for the period spanning 2019 to 2022, generating slightly less than 1 TWh/yr (975.5 GWh/yr)[5].

Indeed, the tidal barrage systems at La Rance (France) and Sihwa (the Republic of Korea) collectively account for over 90 per 100 of the global installed capacity, boasting 240 MW and 254 MW, respectively[6].

While offshore wind is not strictly categorized as oceanic energy, it's commonly grouped with marine technologies[7] due to its location within a similar environment, offering the potential for synergies between the two[8]. Offshore wind resources are extensive, recognized for their superior potential in electricity generation compared to onshore wind energy, owing to consistently higher wind speeds in offshore locations[9]. Despite this, like other marine resources, offshore wind energy remains predominantly underutilized. Of the total 830 GW of installed wind capacity in 2021, a mere 7 per 100 constituted offshore wind farms[10].

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[1] Khan, M. Z. A., Khan, H. A. and Aziz, M., «Harvesting energy from ocean: Technologies and perspectives», *Energies*, 2022, num. 15, 3456.

[2] Taveira-Pinto, F., Rosa-Santos, P. and Fazeres-Ferradosa, T., «Marine renewable energy», *Renewable Energy*, 2020, num. 150, pp. 1160–1164.

[3] IEA-OES, *Annual Report: An Overview of Ocean Energy Activities in 2022*, París, Technical Report, OES-IEA, 2023.

[4] IEA-OES, *Annual Report: An Overview of Ocean Energy Activities in 2021*, París, Technical Report, OES-IEA, 2022.

[5] IRENA, *IRENASTAT Online Data Query Tool*, 2022. Available online: *http://pxweb.irena.org/pxweb/en/IRENASTAT* (accessed on 8 July 2022).

[6] IEA-OES, *Annual Report, op. cit.*, 2022.

[7] Boehlert, G. W. and Gill, A. B., «Environmental and ecological effects of ocean renewable energy development: A current synthesis», *Oceanography*, 2010, num. 23 (2), pp. 68-81

[8] Rosa-Santos, P., Taveira-Pinto, F., LÓPEZ, M. and RODRÍGUEZ, C. A., «Hybrid systems for marine energy harvesting». *Journal of Marine Science and Engineering*, 2022, num. 10, 633.

[9] IEA, *Offshore Wind Outlook 2019: World Energy Outlook Special Report*, París, Technical Report, International Energy Agency, 2019.

[10] IEA, *Wind electricity,* 2022. Available online: *www.iea.org/reports/wind-electricity* (accessed on 3 March 2023).

When discussing the energy potential of ocean energy systems, or any renewable energy source, it is vital to differentiate between theoretical, technical, economic, and sustainable potentials[11]. Presently, the prevailing focus within the literature emphasizes the theoretical and technical potentials of marine renewable energy (MRE), limiting the ability to perform comprehensive and practical evaluations of the true techno-economic and sustainable potential of MRE.

1.1. Types of marine energy

1.1.1. *Tidal*

Tidal marine energy, also known as tidal energy or tidal power, is a form of renewable energy that harnesses the kinetic and potential energy of ocean tides to generate electricity. It relies on the regular rise and fall of ocean tides, which are driven by the gravitational forces of the moon and the sun on Earth's water bodies.

There are several methods to capture tidal energy:

— Tidal stream systems use underwater turbines or similar devices to capture the kinetic energy of moving water. As tides flow in and out, these turbines spin and generate electricity.

— Tidal range systems, also known as tidal barrages, work by trapping water at high tide and releasing it through turbines as the tide recedes. The potential energy of the water is converted into electricity.

— Tidal lagoon systems are similar to tidal barrages but involve creating an enclosed lagoon with a small opening to the sea. As water flows in and out of the lagoon, it drives turbines to generate power.

Tidal energy is considered a reliable and predictable source of renewable energy because it follows a natural and consistent pattern. However, it is location-dependent and is typically more feasible in areas with large tidal ranges, such as certain coastal regions. Tidal energy has the advantage of being highly sustainable and having a minimal environmental impact compared to some other forms of energy generation. The Ocean Energy Council approximates the worldwide theoretical potential of tidal currents to be around 0.5 TW[12]. As per Mourad Nachtane *et al.*[13], the current global exploitable tidal current power, utilizing existing technologies, is estimated to be approximately

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[11] Taveira-Pinto *et al., op. cit.,* 2020.

[12] OEC, *Ocean current energy*, Ocean Energy Council, 2022. Available online: *www.oceanenergycouncil.com/ocean-energy/ocean-current-energy/* (accessed on 15 December 2022).

[13] Nachtane, M., Tarfaoui, M., Hilmi, K., Saifaoui, D. y El Moumen, A., «Assessment of energy production potential from tidal stream currents in Morocco», *Energies*, 2018, num. 11, 1065.

75 GW (equivalent to 177.4 TWh/yr with an assumed capacity factor of 27 per 100). Typically, the viability of tidal stream energy harvesting is feasible in locations where water flow velocities exceed 2–2.5 m/s and water depths range between twenty five and fifty meters[14]. Limited locations meeting these criteria are identified in the UK, Canada, China, the USA, Argentina, Russia, France, Australia, New Zealand, India, and South Korea[15].

1.1.2. *Waves*

Marine wave energy, often referred to as wave power, is a type of renewable energy generated from the movement of ocean waves. It involves capturing the kinetic energy produced by the natural motion of waves in the ocean to convert it into electricity.

There are various methods used to harness wave energy:

— Point absorbers are devices that float on the water's surface and use a buoy that moves up and down with wave motion. The vertical movement drives a generator, converting the kinetic energy into electricity.

— Oscillating water columns (OWCs) use the motion of waves to push air up and down within a chamber. The moving air spins a turbine connected to a generator, producing electricity.

— Attenuators are long, multi-segmented devices that align with the direction of the waves. As the segments move independently in response to wave motion, hydraulic systems or generators convert this motion into electricity.

— Overtopping devices channel waves into a reservoir situated at a higher level than the ocean. As the reservoir fills with water, it's released back to the ocean through turbines, generating electricity.

Wave energy is considered a consistent and predictable source of renewable energy since ocean waves are influenced by wind patterns and tend to be more stable than some other renewable sources, like solar or wind energy. However, similarly to tidal energy, the availability of suitable locations for efficient wave energy generation and the technological challenges in withstanding harsh ocean conditions can impact its widespread implementation. Data found in various literature sources suggests a wide range for the global wave energy resource, estimated to be between 1 to 10 terawatts (which equates to

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[14] Lewis, M., Neill, S., Robins, P. and Hashemi, M., «Resource assessment for future generations of tidal-stream energy arrays», *Energy*, 2015, num. 83, pp. 403–415.

[15] Evans, P. S., *Hydrodynamic characteristics of macrotidal straits and implications for tidal stream turbine deployment*, Ph.D. Thesis, School of Earth and Ocean Sciences, Columbia, SC, USA, 2014, p. 287.

8,766 to 87,660 TWh/yr)[16]. Recent studies have aimed to enhance the accuracy of these estimates for wave energy potential using geospatial software. Initial assessments, which did not consider wave energy direction, projected theoretical potentials of 3.65 TW (equivalent to 32,000 TWh/yr), closely aligning with the 29,500 TWh/yr reported by OES in 2012[17]. Taking wave direction into account, Kester Gunn and Clym Stock-Williams[18] estimated a reduced value of 18,400 TWh/yr for energy potential. Additionally, Borja Reguero *et al.*[19] factored in wave energy direction, establishing a global wave theoretical potential at the continental level (neglecting inner seas) of 16,000 TWh/yr.

1.1.3. *OTEC*

OTEC stands for «Ocean Thermal Energy Conversion». It is a renewable energy technology that harnesses the temperature difference between the warm surface waters of the ocean and the colder depths to generate electricity. OTEC systems utilize this temperature gradient to drive a power cycle, typically consisting of the following key steps:

— Warm surface water heated by the sun is used to vaporize a fluid with a low boiling point, such as ammonia.

— Vaporization and expansion utilises the vapor created from the warm surface water, which is expanded in a turbine, driving a generator to produce electricity.

— Cold water from the depths is typically found several hundred meters below the surface, and condenses the vapor back into a liquid state.

— Repetition of the cycle, taking advantage of the cyclical character of the process, continuously employs the temperature difference to produce energy.

OTEC has the potential to produce consistent and reliable energy as long as there's a significant temperature differential between the warm surface waters and the colder deeper waters. However, it requires specific geographic locations where these conditions are met, and the technology is relatively complex and costly to implement. OTEC is considered a clean and sustainable energy source as it produces electricity without the direct emission of greenhouse gases. Based on an estimated average temperature contrast of 20 Kelvin between

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[16] Taveira-Pinto *et al., op. cit.,* 2020.

[17] OES, *Annual Report 2012: Implementing Agreement on Ocean Energy Systems*, París, Technical Report, Ocean Energy Systems-IEA, 2012.

[18] Gunn, K. and Stock-Williams, C., «Quantifying the global wave power resource», *Renewable Energy*, 2012, num. 44, pp. 296–304.

[19] Reguero, B., Losada, I. and MÉNDEZ, F., «A global wave power resource and its seasonal, interannual and long-term variability», *Applied Energy*, 2015, num. 148, pp. 366–380.

the ocean's surface and its deeper waters, and according to IRENA[20], approximately 100 TW (equivalent to 876,000 TWh/yr) are deemed globally accessible.

1.1.4. *Salinity gradients*

Salinity gradient marine energy, often referred to as osmotic or blue energy, is a form of renewable energy that captures the energy released when freshwater and saltwater mix. This occurs at locations where rivers meet the ocean or where saltwater and freshwater bodies interact, creating a difference in salt concentration known as salinity gradient.

The process involves using membranes that selectively allow ions to pass through while retaining the water. When freshwater and saltwater are separated by these membranes, osmotic pressure is generated as freshwater naturally moves across the membrane to dilute the saltwater.

Salinity gradient energy systems typically involve pressure-retarded osmosis (PRO) or reverse electrodialysis (RED) methods to harness the osmotic pressure created by the saltwater and freshwater interaction. These methods use the generated pressure to drive turbines and generate electricity.

While salinity gradient energy is a promising form of renewable energy, it currently faces technological challenges in designing efficient and economically viable systems. Implementing these systems on a large scale requires specialized membranes and processes that can withstand the harsh conditions of saltwater and freshwater interactions while maintaining efficiency in energy production. Despite the challenges, ongoing research and developments aim to improve the viability of salinity gradient energy as a sustainable and clean energy source. The first estimations of the globally available power in the form of salinity gradients at river mouths were made in the 1970s, and ranged between 1.4 and 2.6TW (12,305–22,776 TWh/yr)[21].

1.1.5. *Offshore wind*

Offshore wind energy is a form of renewable energy generated by wind turbines installed in bodies of water, typically oceans or seas. These wind turbines are situated some distance away from the shoreline, as opposed to onshore wind farms.

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[20] IRENA. *Tidal Energy: Technology Brief.* Abu Dhabi, Technical Report, IRENA, 2014.

[21] Wick, G. and Schmitt, W., «Prospects for renewable energy from sea», *Marine Technology Society Journal*, 1977, num. 5–6, pp. 16–21.

Offshore wind energy is generated using turbines mounted on fixed foundations embedded into the seabed or floating platforms tethered to the ocean floor. These turbines harness the power of wind to spin their blades, converting kinetic energy into electrical energy. The generated electricity is transported through undersea cables to onshore grids for distribution.

The main advantages of offshore wind energy include:

— Stronger and more consistent winds over water, allowing for more reliable energy production.

— Larger turbines and greater capacity, as offshore wind farms can accommodate larger turbines with higher power capacity due to fewer space limitations compared to onshore locations.

— Reduced visual and noise impact of the turbines as they are placed offshore and, therefore, have less visual and noise impact on nearby communities compared to onshore wind farms.

Despite these advantages, offshore wind energy also presents challenges. It involves higher installation and maintenance costs due to the complexities of construction in marine environments, such as the need for specialized equipment and offshore support structures.

The continuous development of technology and ongoing research aim to overcome these challenges, making offshore wind energy a significant contributor to renewable energy production worldwide. In comparison to other forms of ocean energy, the offshore wind industry is considered relatively mature[22]. The first platform was established in Denmark in 1991[23], and a significant milestone was reached in 2009 when Statoil-Hydro and Siemens installed the initial large-scale grid-connected floating wind turbine on the Norwegian coast, at Karmøy. Estimates of the potential for global offshore wind energy vary significantly based on the methodology, assumptions, and limitations of each study. Key factors contributing to these disparities include the defined water depth, power density, and capacity factors[24].

According to Elise Dupont *et al.*[25], the energy potentially available from suitable offshore areas (i.e. the EEZ part up to fifty meters deep) estimated from the global kinetic energy dissipated in the atmospheric boundary layer amounts to 8.35 TW (equivalent to 73,146 TWh/yr).

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[22] Taveira-Pinto *et al., op. cit.,* 2020.

[23] Perveen, R., Kishor, N. and Mohanty, S. R., «Off-shore wind farm development: Present status and challenges», *Renewable and Sustainable Energy Reviews*, 2014, num. 29, pp. 780–792.

[24] Bosch, J., Staffell, I. and Hawkes, A. D., «Temporally explicit and spatially resolved global offshore wind energy potentials», *Energy*, 2018, num. 163, pp. 766–781.

[25] Dupont, E., Koppelaar, R. and Jeanmart, H., «Global available wind energy with physical and energy return on investment constraints», *Applied Energy*, 2018, num. 209, pp. 322–338.

Initial estimates of offshore wind energy resources were constrained by proximity to land and shallow water depths, favouring bottom-fixed foundations. Xi Lu *et al.*[26] employed similar methodologies and obtained estimates of 157,000 TWh/yr and 192,800 TWh/yr, respectively. These studies interpolated between vertical layers of the GEOS-5 database pressure fields, assuming one hundred meter hub heights. The disparity between the studies lay in the turbine power density, at 5.84 MW/km² and 5 MW/km², respectively.

Additionally, offshore wind requires careful environmental impact assessments (EIA) and mitigation strategies to protect marine ecosystems and address potential conflicts with other ocean users. This is critical when evaluating the techno-ecological potential of offshore wind energy, which will have lower values than the technological and even the economical potentials.

1.2. Impacts of marine energy infrastructures

As explained before, regarding all marine energy technologies, techno-ecological potential is what matters, and this is considerable lower than the theoretical potential. For evaluating the techno-ecological potentials it is key to assess the environmental impacts that such technologies have on marine ecosystems. An outline of the most important potential impacts of planned floating offshore wind farms (OWF) in the Mediterranean Sea, including marine protected areas (MPAs), is presented in the following paragraphs.

As at present there is a lack of operational OWF in the Mediterranean Sea[27], comprehensive empirical studies assessing the environmental impacts of such infrastructures are absent for this basin. However, potential impacts during the construction, operation, and decommissioning phases of future OWFs in the Mediterranean Sea can be anticipated by referencing scientific literature from analogous cases in other regions, like the North Sea, the Baltic Sea and the North Atlantic[28]. Nevertheless, the insight gained from these regions in northern Europe are only partially transferable to OWF development in the Mediterranean Sea due to the distinct environmental and socioeconomic

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[26] Lu, X., Mcelroy, M. B. and Kiviluoma, J., «Global potential for wind-generated electricity», *Proceedings of the National Academy of Sciences*, 2009, num. 106, pp. 10933–10938.

[27] Not to talk about the prototype installed off the coast of Apulia, in Italy, from 2007 to 2008, at 113 m of water depth (Barooni, M., Ashuri, T., Velioglu Sogut, D., Wood, S. and Taleghani, S. G., «Floating offshore wind turbines: Current status and future prospects», *Energies*, 2023, num. 16 (1), pp. 1-28.

[28] Bray, L., Reizopoulou, S., Voukouvalas, E., Soukissian, T., Alomar, C. *et al.*,. «Expected effects of offshore wind farms on Mediterranean marine life», *Journal of Marine Science and Engineering*, 2016,num. 4 (18), pp. 1-17.

characteristics of both regions. The main environmental impacts could be summarised in five main entries:

— Species and habitats. This includes seven main aspects. (i) Biodiversity changes: the Mediterranean Sea has the highest proportion of threatened habitats, 32 per 100, well ahead of other seas. (ii) Non-indigenous species: introduced by the increase of human activities in the deployment of OWFs. (iii) Commercial fish and shellfish: populations of commercially exploited fish within safe limits are indicative of a healthy stock, which could be affected by the increase of industrial activities due to the OWF deployment, maintenance and decommissioning. (iv) Food webs: by colonization of atypical communities (sessile benthic species) the food web structure could be modified. (v) Sea-floor integrity: the OWF infrastructure (anchors, mooring systems, heavy chains and cables) will impact the seabed affecting sea-floor integrity. (vi) Hydrographical conditions: alterations in atmospheric and oceanic patterns resulting in shifts in regional primary productivity and the transfer of carbon to the seafloor, along with modifications in pathways for transporting larvae. (vii) Energy, including underwater noise: increase in local water turbidity arising from suspended solids, significant marine noise and vibration from turbines and mounting structures, emission of electromagnetic fields that can affect electrosensitive species, such as marine mammals and bottom dwelling species.

— Threats of OWF to MPAs. Because strong winds are a prerequisite for site selection for the implementation of OWFs, the plans for OWF and MPAs in the Mediterranean Sea can easily overlap, rendering the installation of large OWF projects a challenge. Emphasizing the significance of MPAs in mitigating the impacts of climate change on oceans and easing anticipated challenges, such as diminished food security and rising sea levels, requires fostering intact and diverse ecosystems with abundant species diversity[29]. Notably, MPAs play a vital role in preserving carbon sequestration and storage, serving as a safeguard against the effects of climate change[30]. Any influence of OWFs on Mediterranean MPAs might potentially undermine this crucial function.

— Atmospheric and oceanic dynamics. OWFs hold the potential to alter atmospheric and oceanic dynamics through the influence of structures both above and below the water surface. In specific cases, significant reductions in wind speeds reaching up to 70–90 per 100 have been estimated in the immediate vicinity and downstream of OWFs, as observed in the North Sea[31]. Such a reduction in wind speed can affect both the

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[29] Roberts, C. M., O'Leary, B. C., Mccauley, D. J., Cury, P. M., Duarte, C. M. *et al.*, «Marine reserves can mitigate and promote adaptation to climate change», *Proceedings of the National Academy of Sciences*, 2017, num. 114 (24), pp. 6167–6175.

[30] *Ibid.*

[31] Christensen, E. D., Johnson, M., Sørensen, O. R., Hasager, C. B., Badger, M. *et al.*, «Transmission of wave energy through an offshore wind turbine farm». *Coastal Engineering*,

atmospheric boundary layer and subsequently the surface mixed layer, impacting the photic zone and, consequently, marine primary production. Wind plays a pivotal role in regulating ecosystem productivity in various regions of the Mediterranean Sea, such as the northern Catalan Sea[32]. Notably, strong north-westerly winds in the Gulf of Lions serve as a primary driving force for enhancing nutrient-rich water upwelling.

— Cumulative pressures. While the impact of a single wind farm on a specific wildlife population might be minimal, the combined impacts of multiple wind farms across space and time are likely to magnify the effects caused by other sectors[33]. Cumulative pressures could become significant in the Mediterranean Sea would OWFs proliferate, coupled with pressures arising from other marine activities and users in this region. The Mediterranean Sea has a historical background and continues to face significant threats from multiple uses and stressors, leading to substantial alterations of the marine ecosystem and widespread conflicts among marine users[34]. The introduction of OWFs would further contribute to the pressures already generated by other maritime sectors, including cruises, maritime transport, fisheries and tourism activities.

— Other environmental pressures. The Mediterranean Sea presents particular features that may amplify environmental pressures associated with OWFs, which relate to those already observed in northern European seas. Primarily, the risk of accidents looms significantly. Despite the burgeoning global wind energy production, there remains a substantial gap in scientific and technical literature concerning the analysis of wind turbine accidents[35]. Risks tied to natural hazards, like storms and extreme events intensified by climate change, such as hurricane Gloria in 2020 in the Western Mediterranean[36][37], compound the

2013, num. 82, pp. 25–46; Ludewig, E., *On the effect of offshore wind farms on the atmosphere and ocean dynamics*, Switzerland, Hamburg Studies on Maritime Affairs, num. 31, Springer International Publishing, 2015,p. 162; Akhtar, N., Geyer, B., Rockel, B., Sommer, P. S. and Schrum, C., «Accelerating deployment offshore wind energy alter wind climate and reduce future power generation potentials», *Scientific Reports*, 2021, num. 11(1), 11826.

32 Estrada, M., «Primary production in the northwestern Mediterranean», *Scientia Marina*, 1996, num. 60 (supl. 2), pp. 55–64.

33 Gușatu, L. F., Menegon, S., Depellegrin, D., Zuidema, C., Faaij, A. *et al.*, «Spatial and temporal analysis of cumulative environmental effects of offshore wind farms in the North Sea basin», *Scientific Reports*, 2021, num. 11(1), 10125.

34 Micheli, F., Halpern, B. S., Walbridge, S., Ciriaco, S., Ferretti, F. *et al.*, «Cumulative human impacts on Mediterranean and Black Sea marine ecosystems: assessing current pressures and opportunities», *PLoS ONE*, 2013, num. 8 (12), e79889.

35 Asian, S., Ertek, G., Haksoz, C., Pakter, S. and Ulun, S., «Wind turbine accidents: a data mining study», *IEEE Systems Journal*, 2017, num. 11 (3), pp. 1567–1578.

36 Amores, A., Marcos, M., Carrió, D. S. and Gómez-Pujol, L., «Coastal impacts of storm Gloria (January 2020) over the North-Western Mediterranean», *Natural Hazards and Earth System Science*, 2020, num. 20, pp. 1955–1968.

37 De Alfonso, M., Lin-Ye, J., García-Valdecasas, J. M., Pérez-Rubio, S., Luna, Y. *et al.*, «Storm Gloria: sea state evolution based on in situ measurements and modelled data and its impact on extreme values». *Frontiers in Marine Science*, 2021, vol. 8, 646873.

risks attributed to wind turbine accidents. These include fire incidents, the potential fall of the turbine structure into the sea, and collisions involving ships[38].

Understanding and mitigating these environmental impacts require thorough EIAs, strategic planning, and proper management practices during the planning, construction and operational phases of offshore wind farms in the Mediterranean Sea. Environmental monitoring, habitat restoration, and the implementation of mitigation measures are crucial for reducing potentially negative impacts and promoting the sustainability of offshore wind energy development.

2. SEAFLOOR ENERGY INFRASTRUCTURES FRAMED WITHIN THE CITY BLUE ECONOMY: CHALLENGES AND OPPORTUNITIES

The seafloor is being used increasingly to support critical infrastructures, such as oil rigs, pipelines, windfarms, communication and electrical cables, and many more. The current functioning of industrialized societies would not be possible without such infrastructures. Despite of congestion in specific locations, there is still plenty of room for the deployment of seafloor infrastructures. Commonly, the seafloor offers better safety conditions to such infrastructures that land deployments. Furthermore, seafloor installations prevent impacts on land ecosystems, which is a highly sensitive matter, and ensure connectivity across large distances, such as entire ocean basins. Seafloor deployments can also help avoiding or reducing protests by groups that are against some types of infrastructures.

One drawback of seafloor infrastructures is their potential impact on marine ecosystems and organisms. EIAs are now mandatory in many countries for marine infrastructural projects, with the aim of minimizing such impacts to the smallest possible extent. In critical cases, EIAs can lead to new routings or placements of given infrastructures, or even to their dismissal. Monitoring programs are current practice too, so that the status of the ecosystems is regularly assessed according to agreed standards. Infrastructure decommissioning is a highly relevant issue as well, that is receiving much more attention at present than it was the case in the past.

The greatest challenge mankind is facing nowadays is global warming caused by the massive release of greenhouse gases to the Earth atmosphere, most of which come from the burning of fossil fuels. This

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38 Biehl, F. and Lehmann, E., «Collisions of ships with offshore wind turbines: calculation and risk evaluation». In Köller, J., Köppel, J. and Peters, W. (eds.), *Offshore Wind Energy*, Springer, Berlin, Heidelberg, 2006, pp. 281-304.

issue connects directly to the very heart of the global energy system. There is general consensus on the urgent need to decarbonize our societies and industries, so that the current global warming trend can be abated. One way of contributing to such an abatement is changing consumption habits, especially in industrialized countries. Another one is reducing the usage of fossil fuels and investing in renewable energies. As described in previous sections, there is plenty of opportunities to sustainably develop renewables at sea, subsequently contributing to climate change mitigation.

In short, our world as it is today would collapse without the existing seafloor infrastructures, which will likely increase in the future to come to satisfy the needs of a continuously growing human population while taking care of the health of our planet.

2.1. Gas infrastructure in Spain: the position of Barcelona

Spain has a rather advantageous position compared to other European countries in terms of gas infrastructure, with seven LNG regasification terminals along its shoreline, both in the Mediterranean and the Atlantic, and a robust grid of distribution pipelines, still being further developed. One of this LNG terminals, dating from 1969, is located in Barcelona and is owned by Enagas. With a storage capacity of 0.35 million tons (Mt), the Barcelona terminal currently has a regasification capacity of 602.99 bcf/annum (billion cubic feet)[39].

The strategic importance of LNG terminals in Spain has been demonstrated after the reduction in gas supply to countries in central Europe by the Russian Federation as a consequence of their support to Ukraine in the on-going war. LNG terminals allows diversifying and ensuring the supply for the Spanish energy system.

However, due to the lack of international connections with France and the rest of Europe, Barcelona is a dead end of the Spanish LNG network. This could be viewed as an anomalous situation as such connections do exist through Irún in the Basque Land and Larrau in Navarra. Plans, such as MidCat, to connect the gas network in Spain with southern France along the so-called land «Mediterranean corridor» have been discussed at various stages but at present this option seems to be abandoned. Would some sort of gas connection be established sometime in the future with southern France, either by land or sea, Barcelona would move from its current dead end condition to reinfor-

[39] *www.offshore-technology.com/marketdata/barcelona-lng-regasification-terminal-spain/?cf-view*: summary data on Barcelona LNG Regasification Terminal (accessed on 6 November 2023).

cing its role and ambition as a strategic hub in southern Europe, also for energy.

This would be highly relevant not just for gas but also for electricity production in neighbouring countries, as illustrated by the French electrical mix, which mostly relies on nuclear power (~72 per 100)[40]. However, there are powerful geopolitical and economic issues at play. For instance, France could have little or no interest to open the door to a supplier, eventually a competitor, from the south. Instead, this country may prefer protecting its nuclear energy production —and associated sales— from any competition.

2.2. Barcelona push for Blue Economy

In line with EU priorities, both Catalonia and Barcelona consider the Sustainable Blue Economy as a strategic priority for the years to come, as illustrated, for instance, by the report on the economical dimension of the Blue Economy in Catalonia[41] or the city council government measure to boost the Blue Economy[42]. This should be embedded in the current arm-wrestling amongst several large coastal cities in Europe and beyond to become «Blue Economy capitals». Barcelona certainly has some good cards to succeed in that endeavour as the Blue Economy capital of the Mediterranean Sea in direct competition with other cities such as Istanbul or Genoa.

Let's illustrate this view with some numbers. For instance, the port of Barcelona, with 1,200 Ha to the service of the Blue Economy, is the main logistic hub in southern Europe. It is the first in the Mediterranean Sea in cruise passengers; the first in Spain by cargo economic value, turnover, import/export loads, and international connections; and the eighth in Europe in containers' volume. It also conveys the 23 per 100 of the foreign trade of Spain and the 34 per 100 of the foreign sea trade of containers in Spain. In 2022 the port of Barcelona recorded more than 70 million tons of goods with a market value in excess of 120,000 million Euros of foreign trade[43].

According to the most recently available data, the overall turnover of the Blue Economy in Barcelona —of which the port is a major ac-

[40] *www.ecologie.gouv.fr/production-delectricite*: electrical production in France (accessed on 6 November 2023).

[41] Generalitat de Catalunya, *L'Economia Blava a Catalunya. Dimensió econòmica del sector a Catalunya*, Barcelona, Departament d'Acció Climàtica, Alimentació i Agenda Rural, 2023, p. 105.

[42] Ajuntament de Barcelona – Barcelona Activa, *Mesura de Govern – Impuls de l'Economia Blava a Barcelona*, Ajuntament de Barcelona, 2021, p. 74.

[43] Ajuntament de Barcelona – Barcelona Activa, *Economia Blava de Barcelona en xifres 2022*, Ajuntament de Barcelona, 2021, Infografia.

tor— was close to 4,000 million Euros, and directly employed more than sixteen thousand people[44]. However, the reader should be aware that the numbers provided do not capture completely the dimension of the Blue Economy in the city, as some key sectors, such as tourism, couldn't be fully accounted.

Furthermore, Barcelona is hosting an increasing number of high impact events in the Blue Economy field, which are bringing in not only visitors and income, but also strong international visibility and investment. This is well illustrated by recurrent events such as the *Saló Nàutic Internacional*, the Leading Exhibition for Logistics, Transport, Intralogistics and Supply Chain in Southern Europe (SIL), the Seafood Expo Global, and also by events such as the World's Ocean Council Sustainable Ocean Summit (SOS) and the Global Blue Finance Summit (BlueFIN) in October 2022, or the upcoming UN Ocean Decade Conference in April 2024, and the America's Cup from August to October 2024. Last but not least, some leading international organizations and private companies are also establishing their headquarters and innovation leading branches in Barcelona or nearby, as shown by the World's Ocean Council (WOC) or the Triton Submersible Supercentre, which is the company that built the most performant ultra-deep water submersible to date, *named Limiting Factor*.

2.3. A green underwater energy corridor in the northwestern Mediterranean Sea

In 2022, after discarding the MidCat land connection for gas transport across Catalonia to France, the Spanish and French governments discussed plans for the potential layout of a submarine pipeline from Barcelona to Marseille in the near future. The name given to such a connection was BarMar, which was later embedded within a more ambitious project named H2Med that joins France, Portugal and Spain[45]. The idea is building a unique «green energy corridor» for hydrogen with an estimated cost of 2,500 M€. The strategic objective is to lessen the dependence on poorly reliable energy providers, namely the Russian Federation, while decarbonizing and denuclearizing energy production to the benefit of EU member states.

The practical implementation of the H2Med project including the BarMar component requires for EU and national hydrogen strategies to be clarified and, eventually, scaled up. The aim is for the EU to achieve

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[44] *Ibid.*

[45] *www.lamoncloa.gob.es/lang/en/gobierno/news/Paginas/2022/20221216_h2med-green-hydrogen-hub.aspx*: note from the Spanish government on the submission of theH2Med application as an EU Project of Common Interest (accessed on 6 November 2023).

40 GW of electrolyser capacity to produce green hydrogen by 2030. Regarding plans for green hydrogen, Spain and France are amongst the leaders in the EU, according to GlobalData research. Actually, Spain aims at installing 4GW by 2030, whereas Portugal expects to contribute to the EU goal with 2–2.5GW. These figures do not look particularly ambitious[46]. In other words, this does not seem a project to address the energy crisis in the short term but in the mid and long terms.

One key aspect is the routing of the BarMar pipe, or pipes. Depending on the option selected it could be from 365 to 475 km long plus anchoring. The Barcelona to the maritime French border is the most challenging segment as the continental shelf is narrow and incised by several deep submarine canyons that compartmentalize it into several subsegments. Both the shelf and the canyons in this southern segment host a rich biodiversity and protected habitats, including cold-water corals. A particularly critical crossing would be the Cap de Creus Canyon, where strong seasonal currents leading to seafloor abrasion and erosion occur[47] [48]. In addition, canyon heads and walls are prone to density flows and submarine landslides[49] [50] [51]. Another challenging crossing would be La Fonera Canyon, which in addition of being particularly deep, steep and intricate hosts an intensive bottom trawling fishery[52].

The information above illustrates the need for a very careful planning of the BarMar routing. Actually, a deep water route could have some advantages, as it would avoid the submarine canyons in the southern segment and harming the unique habitats they host. This plan would also minimize interference with human activities, such as bottom trawling over the outer shelf and continental slope[53]. Alternative options to the shallow water one could follow a south-eastward,

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46 *www.energymonitor.ai/tech/networks-grids/the-french-spanish-barmar-pipeline-will-do-little-to-address-the-energy-crisis-in-the-short-term/?cf-view*: information on the French-Spanish «BarMar» pipeline (accessed on 6 November 2023).

47 Canals, M., Puig, P., Heussner, S., Durrieu De Madron, X., Palanques, A. *et al.*, «Flushing submarine canyons», *Nature*, 2006, num. 444, pp. 354-357.

48 Puig, P., Palanques, A., Orange, D. L., Lastras, G. and Canals, M., «Dense shelf water cascades and sedimentary furrow formation in the Cap de Creus Canyon, northwestern Mediterranean Sea», *Continental Shelf Research*, 2008, num. 28, p. 2017-2030.

49 Canals, M., Lastras, G., Urgeles, R., Casamor, J. L., Mienert, J. *et al.*, «Slope failure dynamics and impacts from seafloor and shallow sub-seafloor geophysical data: Case studies from the COSTA project», *Marine Geology*, 2004, num. 213 (1-4), pp. 9-72.

50 Sultan, N., Cochonat, P., Canals, M., Cattaneo, A., Dennielou, B. *et al.*, «Triggering mechanisms of slope instability processes and sediment failures on continental margins: a geotechnical approach», *Marine Geology*, 2004, num. 213 (1-4), pp. 291-321.

51 Sultan, N., Gaudin, M., Berne, S., Baztán, J., Canals, M. *et al.*, «Analysis of slope failures in canyon heads: Example from the Gulf of Lions», *Journal of Geophysical Research*, 2007, num. 112, F01009.

52 Puig, P., Canals, M., Company, J. B., Martín, J., Amblas, D., Lastras, G. *et al.*, «Ploughing the deep seafloor», *Nature*, 2012, num. 489, pp. 286-290.

53 *Ibid.*

contour-normal line straight from Barcelona till reaching the deepest area at about mid-distance from the northern coast of Mallorca, in the Balearic Archipelago, to then roughly turn north to north-east directly towards either the continental shelf edge in the middle of the Gulf of Lion arch or to Marseille. Both such deep-water routing options would reach maximum depths of about 2,550 m and be substantially longer (455 to 475 km) than the shallow water choice.

Contrary to the southern segment —and taking advantage of the large width of the Gulf of Lion shelf—, the French segment could be laid down entirely at depths less than 150 m deep, would a shallow water option be selected, or partly, would the intermediate deep-water option be prioritized.

The reader should be also aware of the French government plans for a large-scale development of offshore windfarms in the Gulf of Lion shelf, for which abundant information is available[54], [55]. The ambition of such developments minimizes the ones planned by the Spanish Government on the outer shelf off the Bay of Rosses, in between *Cap de Creus* and *La Fonera* submarine canyons to the north and south, respectively[56]. Therefore, it could be that in the 2030 horizon the maritime region from Barcelona to Marseille become a prime energy and distribution area in southern Europe. How BarMar and offshore windfarms will eventually interact is not clear yet. In fact, the overall H2Med project faces both serious technical and economic challenges, which be discuss in the following section.

2.4. Challenges and opportunities

To say the truth, we have detected a noticeable degree of low voice scepticism amongst potential players in the H2Med project. Some see it as a mere political declaration, i.e. as a simple kick forward of the time.

Of course, such a large infrastructure, would it see light, would require large scale port facilities that only Barcelona and Marseille can offer in the region, which could foster economic growth and employment. Some of the questions that are over the table follow:

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[54] *www.eoliennesenmer.fr/facades-maritimes-en-france/facade-mediterranee*: marine offshore windfarms in the French Mediterranean façade (accessed on 6 November 2023).

[55] *www.eoliennesenmer.fr/facades-maritimes-en-france/facade-mediterranee/deux-projets-en-mediterranee*): marine offshore windfarms in the French Mediterranean façade with timeline (accessed on 6 November 2023).

[56] MITECO, *Real Decreto 150/2023, de 28 de febrero, por el que se aprueban los planes de ordenación del espacio marítimo de las cinco demarcaciones marinas españolas*, Madrid, *BOE* núm. 54 de 4 de marzo 2023, pp. 32350-32578.

— How long will it take for the needed technical components and solutions to be developed and made operational? At which cost? Where is the knowledge needed and/or how to develop it?

— Would Barcelona simply become a commodity provider to northern Europe, i.e. a southern supplier of a large marine renewables and hydrogen hub in Marseille from where exports will be made to the rest of Europe?

— At the end, wouldn't it be more profitable producing hydrogen where it will be consumed, or nearby, or doing this where it's cheaper and then carry it either by pipe or vessel?

— Why not building a regasification plant in Marseille or around instead of a tremendously expensive submarine pipeline from BCN?

— When will Europe be ready for hydrogen massive transport and usage?

— How to solve the challenge of efficiently connecting Marseille to the north of Europe given that current gas pipelines from one place to the other do not admit high percentages of hydrogen?

— Will the EU provide the 30-50 per 100 share of the funds needed for H2Med, including BarMar, as a Project of Common Interest (PCI) following the proposal submitted in December, 2022,[57]?

Of course, the H2Med / BarMar project also involves a number of challenges, amongst which:

— As an unprecedented and truly pioneering proposal, such an undersea pipeline brings complexity to the whole project.

— Hydrogen is to a large extent meant to meet industrial needs: hydrogen pipelines could make sense if they help meet the needs of industrial zones vs. citizen's domestic needs.

— Time frame: highly unlikely to become reality before 2030, which would be the intended deadline according to political declarations.

— The risk of discarding «the old» before building «the new» and ensure that H2Med / BarMar are fully operable at the scale needed.

— Current poor development of the hydrogen industry.

— Sufficient water resources must be secured to sustain a massive production of green hydrogen.

— Powering by renewables is largely discontinuous, would it be applied to of green hydrogen production.

— BarMar for hydrogen transportation will be longer to build and more expensive than a conventional gas pipeline including MidCat, but will have a longer lifetime: not a short-term solution but a long-term investment.

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[57] *www.lamoncloa.gob.es/lang/en/gobierno/news/Paginas/2022/20221216_h2med-green-hydrogen-hub.aspx*. Last update: H2Med is one of the 68 hydrogen projects amongst which the EC plans to split 50,000 million Euros.

— Need to minimize environmental impacts to the marine environment.

The following opportunities, at various levels, appear when digging into the H2Med / BarMar project, as illustrated in the following lines:

— Achieving energetic independence for Europe (at a cheaper cost than current gas imports, e.g. from the US).
— Take advantage of the renewables' potential in Spain and Portugal for cheaper hydrogen production.
— Positioning in the green hydrogen value chain vs. RTD and infrastructure developments (e.g., 25 per 100 of the energy to be conveyed through clean hydrogen in Europe in 2050). Several «green hydrogen valleys», also referred to as «clusters» or «corridors», are taking place in Spain, including one in Tarragona, southern Catalonia, to produce hydrogen from renewables and water[58].
— Enhancement of the strategic positioning of Barcelona and Tarragona ports mainly.
— Sectorial economical activation and regional and local returns including logistics and industry for design, manufacturing, installation, servicing and so on.
— Job creation and maintenance, both direct and indirect, involving high added value positions.
— Helping the transition of the hydrocarbon-based industry (e.g., the petrochemical industry together with most industrial sectors) to other Earth-friendly forms of energy production.

Finally, nowadays any project on energy infrastructures in the short, mid and long term must rely on five pillars to deserve a worth-doing investment, which are:

— Offering viable future solutions.
— Improving supply security.
— No increase of the final cost for the consumer.
— Contribute to the energy transition.
— Be sustainable and environmentally friendly.

RESUMEN: En este capítulo se analiza el mar y, en particular, el mar Mediterráneo, teniendo en cuenta el suministro y el transporte de energía. En la primera parte del capítulo se explican las diferentes fuentes de energía renovable marina, a la vez que se introducen sus potenciales impactos sobre el medio ambiente y los ecosistemas del

[58] *www.nationalgeographic.com.es/economia-circular/estos-son-principales-proyectos-para-producir-hidrogeno-verde-espana_18710*: main projects to produce green hydrogen in Spain (accessed on 6 November 2023).

área mediterránea. En la segunda parte, se presentan el transporte de energía y sus infraestructuras necesarias, debidamente enmarcadas en el tránsito hacia una Economía Azul sostenible, considerando también retos y oportunidades.

PALABRAS CLAVE: energías renovables marinas; impactos ambientales; hidrógeno verde; infraestructuras del fondo marino; Barcelona.

ABSTRACT: In this chapter, the sea and, in particular, the Mediterranean Sea, is analysed considering the supply and transport of energy. In the first part of this chapter the different sources of marine renewable energy[59] are explained, while its potential impacts on the environment and the ecosystems of the Mediterranean area are also introduced[60]. In the second part, the energy transport and their required infrastructures will be exposed, duly framed in the move for a sustainable Blue Economy, also considering challenges and opportunities.

KEYWORDS: marine renewable energy; environmental impacts; green hydrogen; seafloor infrastructures; Barcelona.

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[59] Samsó, R., Crespin, J., García-Olivares, A. and Solé, J., «Examining the potential of marine renewable energy: A net energy perspective», *Sustainability*, 2023, num. 15, 8050.

[60] Lloret, J., Turiel, A., Solé, J., Berdalet, E., Sabatés, A. *et al.*, «Unravelling the ecological impacts of large-scale offshore wind farms in the Mediterranean Sea», *Science of the Total Environment*, 2022, num. 824, 153803.