Energy supply from sea wave, currents, and tides

By Michele Mossa

Environmental conservation and biodiversity preservation are critical considerations when discussing renewable energy sources. Traditional energy sources such as coal, oil, and natural gas have a significant impact on the environment, contributing to global warming, air pollution, and the depletion of natural resources.

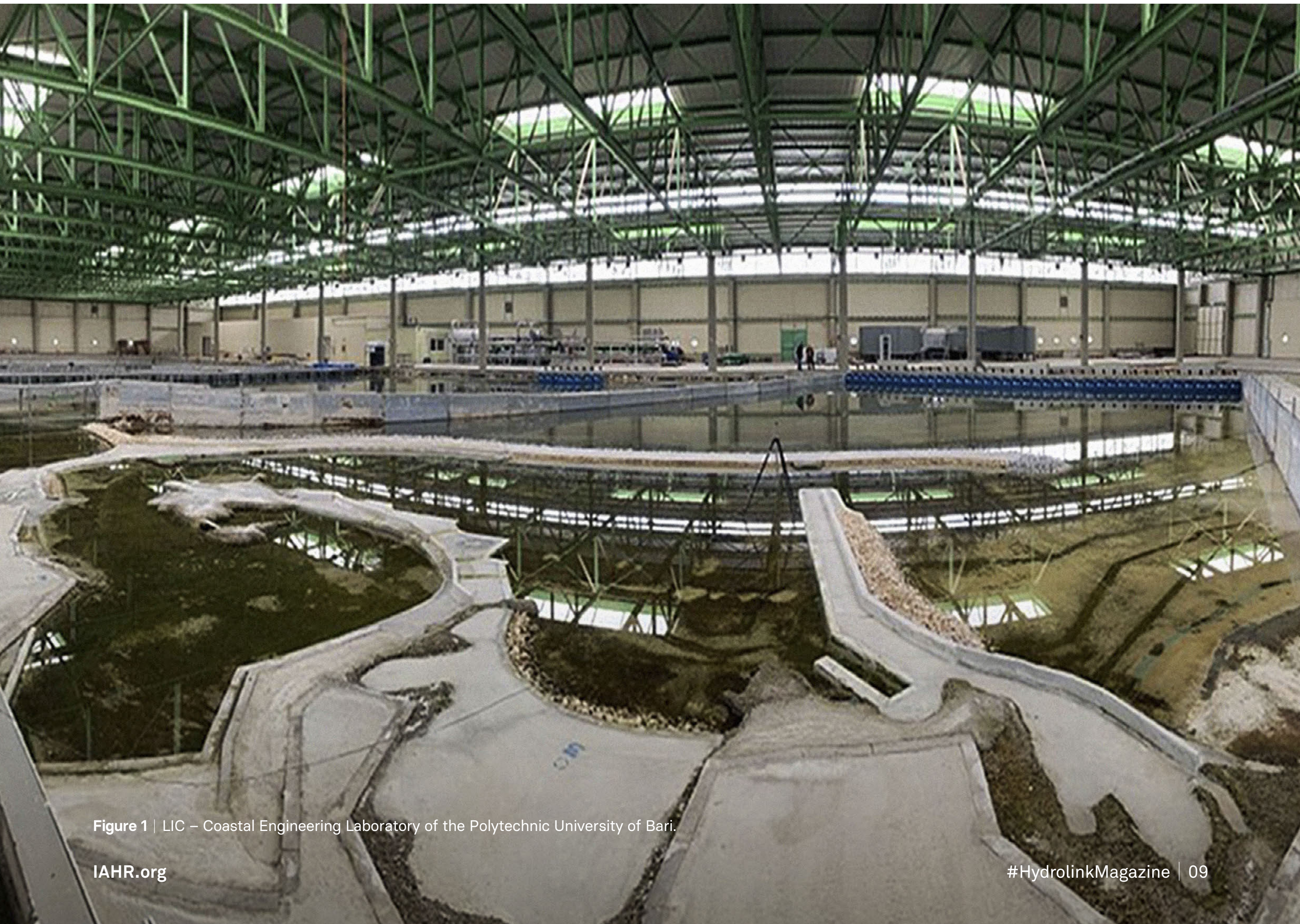

Figure 1 | LIC – Coastal Engineering Laboratory of the Polytechnic University of Bari.

Integrating renewable energy sources into the framework of biodiversity and global changes is essential. Current research has advanced our understanding of the positive correlation between biodiversity and ecosystem functionality, yet significant gaps remain in our knowledge of these relationships. The concept of "One Health" highlights the interconnectedness of human health, animal health, and environmental health. The One Health approach involves collaboration among various disciplines, including medicine, veterinary science, environmental science, and public health, to address health issues comprehensively and holistically.

Renewable energies are moving in this direction. They come from natural sources that are replenished faster than they are consumed. Sunlight and wind, for example, are continually replenished. Renewable energy sources are abundant and pervasive.

However, it is important to recognize that renewable energies can also impact the environment if not properly planned and managed. For instance, the construction of large solar or wind installations could affect natural habitats and disturb wildlife populations. Therefore, conducting thorough environmental assessments and adopting sustainable development practices are crucial when implementing renewable energy projects.

The renewable energy sources recognized and defined by the United Nations include solar energy, bioenergy, wind energy, ocean energy, geothermal energy, hydropower, and others. It is important to note that this list is not exhaustive but provides a useful overview of the situation. Focusing on ocean energy, specifically renewable energy sources from marine currents and waves, Wave Energy Converters (WECs) offer several significant environmental benefits. Firstly, they harness wave and sea current energy, a renewable resource that does not deplete natural reserves, which helps reduce reliance on fossil fuels, lower greenhouse gas emissions, and combat climate change. Secondly, WECs have a low carbon footprint as they do not emit greenhouse gases during electricity generation, unlike fossil fuel-based plants, thereby reducing air pollution and environmental degradation. Thirdly, when properly designed and located, WECs have minimal impact on marine ecosystems, unlike some other renewable energy sources. Proper planning ensures minimal environmental impact. Fourthly, WECs contribute to energy security by diversifying the energy mix and reducing reliance on imported fuels. Finally, WECs can help mitigate coastal erosion by dissipating wave energy, thereby aiding coastal protection and climate change adaptation. Overall, WECs offer a promising avenue for sustainable energy generation with minimal environmental impact, essential for a cleaner and more resilient energy future.

Nevertheless, several challenges remain. Sector studies have highlighted obstacles that delay the development of marine renewable energy. Key gaps to address include developing technologies to improve plant operability and maintenance, establishing a regulatory framework for the construction and operation of these plants, and securing funding programs for marine renewable energy development.

Necessary actions include:

- Improving technologies and devices for the production, storage, and distribution of marine energy and integrating different forms of renewable energies (wind-tidal-wave);
- Defining methodologies for site selection, monitoring, and mitigating the impacts of structures on the marine environment;
- Designing plants that account for end-of-life effects (life cycle thinking approach);
- Integrating renewable energy extraction with sustainable aquaculture production (e.g., bivalve mollusks) at the plant, which can also serve as an Other Effective Conservation Measure (OECM).

Thus, incentivizing research in this sector is crucial to overcoming barriers and realizing the benefits of marine renewable energy.

In Italy, the research landscape is particularly noteworthy. The Network for Energy Sustainable Transition (NEST) partnership (https://fondazionenest.it/), funded by the European Union (EU) under the National Recovery and Resilience Program (PNRR), is a significant initiative. Approved by Italy in 2021 as part of the EU's effort to revitalize the economy post-COVID-19, this program aims to foster green and digital development. The Polytechnic University of Bari serves as the hub for this research and technology transfer program, involving collaborative activities with sector companies. Additionally, the latest National Research Program (2021-2027) of the Ministry of University and Scientific

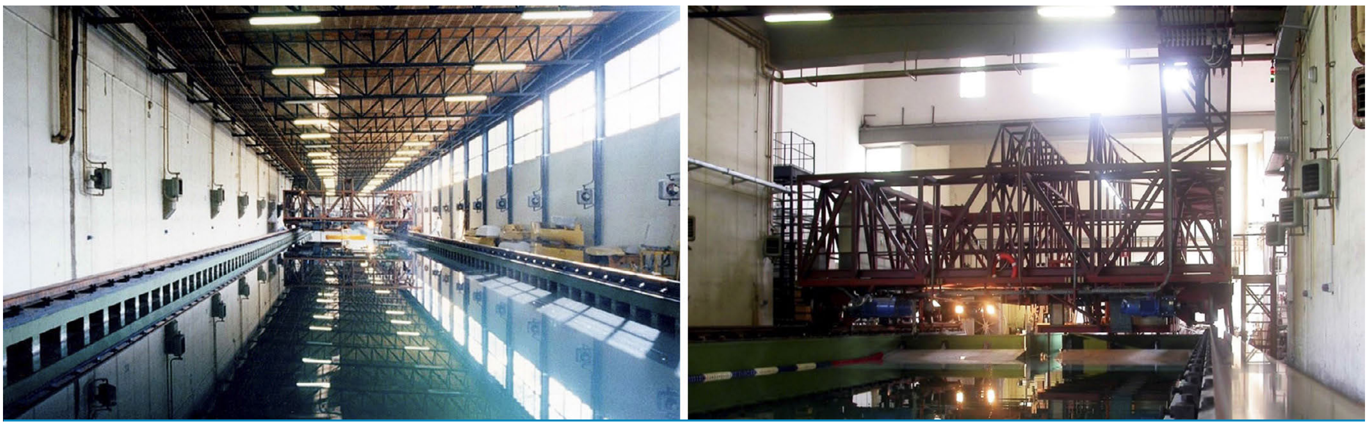

Figure 2 | Tank with bridge crane of the University of Naples "Federico II".

Research, aligning with European guidelines, emphasizes the central role of marine ecosystems as a resource and an opportunity. However, developing a blue economy must address the environmental pressures it entails. Sustainable resource use requires solutions that protect and preserve marine ecosystems.

Research must advance sustainability in current infrastructures and design new green and smart infrastructures, in line with the concept of a smart bay—natural laboratories where research, technology, tourism, and aquaculture collaborate. For example, the PRIN PNRR 2022 project titled Sea Wave Energy Converters and MARine Tidal Turbines (SMART), led by Principal Investigator Michele Mossa, aims to contribute fundamentally through advanced research and technology transfer. It focuses on integrating energy recovery systems from marine currents, waves, and tides within marine ecosystems. Although systems for energy recovery from marine currents and waves currently have high technological readiness levels (TRLs) [3-7], they are still far from achieving the highest TRLs [8-9], associated with operational prototype deployment. Challenges include cost-effectiveness, reliability, manufacturability, operability, and economic feasibility, with the goal of reducing the Levelized Cost of Energy (LCOE).

The research team will conduct numerical and experimental studies using laboratories such as, for example, the LIC – Coastal Engineering Laboratory of the Polytechnic University of Bari (**Figure 1**), the tanks of the University of Naples "Federico II" (**Figure 2**) and the University of Catania, physical models, and field infrastructures in the Strait of Messina and the Mar Piccolo of Taranto. The aim is to enhance knowledge of hydrodynamics, the fatigue life of tidal turbine components, and the long-term effects of marine fouling–such as barnacles, algae, and debris–on turbine blades' performance. Special attention will be given to studying the turbulent wake downstream of the turbines to assess its impact on marine fauna and flora.

Of great interest are also solutions that combine coastal erosion protection (based on Nature-Based Solutions or low-impact techniques) with the optimal production of energy from wave motion. Anthropogenic pressure, combined with natural factors, has significantly contributed to the deterioration of environmental quality in coastal areas and initiated erosive dynamics, leading to the retreat of sandy coastlines and the instability of rocky shores. It is estimated that 24% of the world's sandy beaches experience erosion at rates exceeding 0.5 m/year. The primary natural factors contributing to coastal erosion include wind, wave motion, currents, the lack of fluvial sediments in the sea, land movement, and rising average sea levels. Major anthropogenic factors are related to infrastructure development and residential and industrial settlements. In this context, the research program titled "A Metamaterial-Based Device for Attenuation of Surface Gravity Waves," led by Principal Investigator Miguel Onorato, with Vice Principal Investigator Michele Mossa and Paolo Pezzutto from the CNR – Institute for Biological Resources

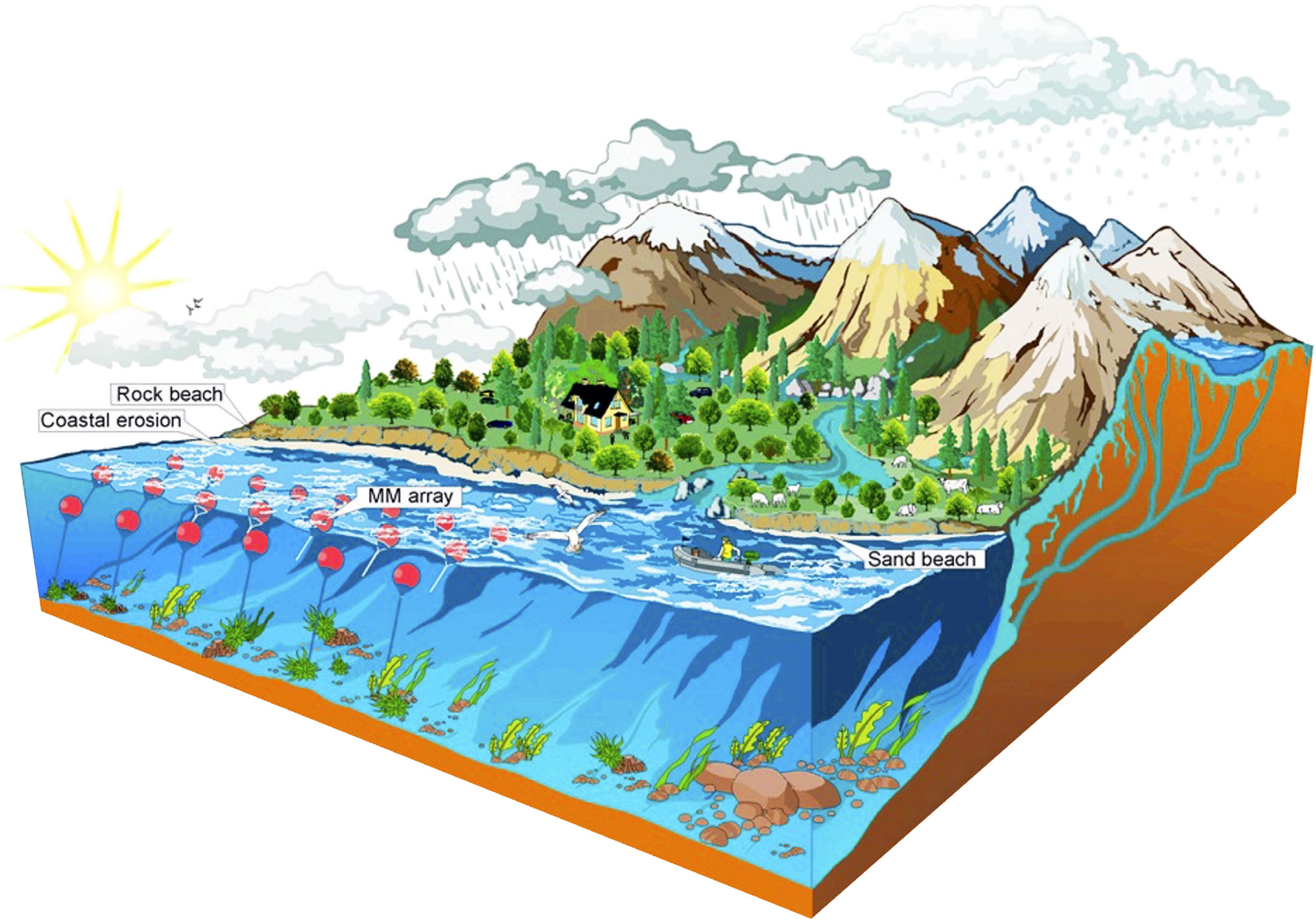

Figure 3 | Forced by the waves, the pendulums oscillate and release their energy into the water in the form of turbulence, which is subsequently dissipated as heat. Part of the energy may also be reflected. The figure shows the device positioned in a coastal environment.

and Marine Biotechnologies in Ancona, aims to develop and test a new device based on the concept of Metamaterials in a controlled maritime hydraulic laboratory environment (LIC – Coastal Engineering Laboratory of the Polytechnic University of Bari). Metamaterials are engineered structures designed to interact with waves and manipulate their propagation properties, such as phase and group velocity, or to produce effects like reflection and absorption. Initially developed for electromagnetic and acoustic waves, they are now applied in various fields of physics and engineering, including seismic protection, noise reduction, and coastal defense (**Figure 3**).

In conclusion, the ultimate goal is to design and develop a new generation of tidal energy converters capable of integrating into marine ecosystems while minimizing their impact and preserving functionality and performance over the long term. As seen, another objective is to explore nature-based solutions that could also contribute to clean energy production.

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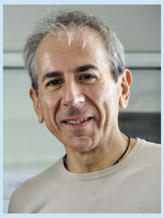

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Further information is available on the website: https://www.michelemossa.it/en/

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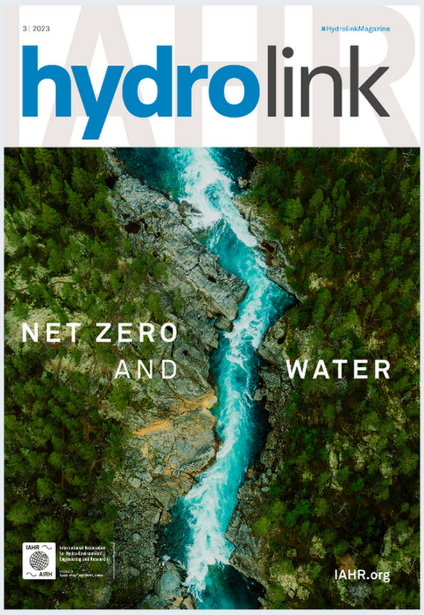

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