Preliminary document - Report for blue energy potential analysis

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Abstract

Blue Energy (BE) potential is widely investigated nowadays to find the most appropriate solution to harness this vast potential stored in our seas and oceans. Project COASTENERGY aims to foster the development and integration of BE technologies in urban coastal areas and ports. Blue Energy potential evaluation and pre-feasibility study of selected pilot locations analysis consist of two separate reports. In this, the first part, blue energy potential is evaluated with the technology assessment for the pilot locations on both sides of the Adriatic. Results of this analysis were used for the selection of the most appropriate technology whose energy potential will be assessed in the second part, alongside the proposal for potential pilot locations.

1. Introduction

The global energy system is changing, due both to an ever-increasing demand driven by the increase in living standards and to the greater environmental awareness by the public opinion, which is reflected in the Paris agreement after COP21. In the energy sector, renewable energies and additions of nuclear capacity provide most of the growth in demand, while the energy mix is being redefined.

Affordable, safe and sustainable energy systems will gradually integrate more diversified energy sources and will depend substantially on distributed generation, thus opening up the market to innovative technologies and smarter renewable energy.

The European Commission and several experts have proposed a long-term vision to address the challenges posed by the decarbonisation of the European energy system and a binding policy package (climate and energy package) have been launched, decided, implemented, and reformed. A combination of tools has been designed to overcome distribution barriers and allow burden-sharing between the Member States, and synergies have been created to mutually reinforce the objectives of the package.

However, Member States still play a crucial role in determining the success of Community policies, while national plans represent a potentially valuable innovation that allows for a more coherent harmonization of the reform of European energy governance, regional policy and cooperation, and long-term climate protection goals.

In this context, ocean energy is recognized to have great potential, although it still requires significant cost reductions. Larger demonstration projects should be facilitated to support their development, from basic and applied research to final commercial distribution. To this end, international cooperation between the various levels of government and with the private sector is recommended, which would help predict new business models and create market opportunities for the benefit of both producers and users of technologies, while contributing to the transition to cheaper energy systems.

Stakeholders complain about their limited involvement in policy design as one of the causes of the weakness of policy penetration in the sector. Furthermore, a lack of coherence between the policies of the Community and those of the Member States is reported, as regards the financial instruments implemented, which are presumed to be temporary and necessary only until commercial maturity is reached. The creation of enabling conditions is still largely a responsibility of each Member State, and the perceived risk that local contingencies may limit development opportunities is still high.

Despite the important position acquired by international experts, Croatia and Italy's progress in the ocean energy sector is still under-represented at the European level, both as regards innovative research and the implementation of devices.

Targeted political interventions and national investments are now crucial for the exploitation of the sector's potential in terms of economic growth, creation of highly qualified jobs, and strategic positioning of the Italian industry in the competitive global market.

The vitality and commitment of a consolidated community of actors from research institutes, SMEs and industry provide a solid basis for effective public policy intervention, supporting both research and a variety of related and downstream businesses, which would allow the downsizing and access to the international market.

As recognized in the EU's strategic ocean energy roadmap, the design and implementation of innovative financing instruments to effectively channel public and private investment are no longer deferable. Access to capital is the main challenge facing the ocean energy sector, which requires the design and implementation of new solutions for capital unlocking and access to EU funding.

National support policies are explicitly required in EU recommendations and directives, which establish a common framework for the Member States regarding the promotion of the use of energy from renewable sources (EU Directive 2009/28 / EC). National intervention is also needed to meet the EU requirements for maritime spatial planning and integrated coastal management by Member States (Directive 2014/89/EU).

This report is part of the project **"COASTENERGY - Blue Energy in ports and coastal urban areas"**, financed under the Italy-Croatia CBC Programme, priority axis Blue innovation. In this first report where Blue Energy potential is analysed for the pilot areas by conducting the technical and regulatory review, and energy potential and technology assessment. In this first section, brief information about the project is given, alongside the main goals and objectives. Moreover, the purpose of such analysis is given according to the project demands, and finally, the used methodology is elaborated. Potential analysis and technology evaluation from this report will be used for the pre-feasibility study and pilot location selection which are objectives of the second report.

1.1. About the project

Project COASTENERGY aims to foster the creation of a favourable environment for more significant deployment of devices designed to harness the Blue Energy (BE) potential. The project is focused on wave and thermal energy converters, which can be integrated into coastal and ports infrastructure. Therefore, the project will seek to produce a joint strategy and build a common knowledge framework that could initiate the dialogue among various stakeholders to boost investments in Blue Energy projects. Since the installation of such devices has an impact on local marine and ecosystems and the landscape, inclusion of citizens, maritime-related activities and public authorities is inevitable. This is done by establishing local coastal HUBs on BE, which aims to initiate discussion on benefits and opportunities that may arise from the utilisation of BE potential. Besides, cross-border cooperation between Italy and Croatian partners from both sides of the Adriatic Sea aims to promote the exchange of good practices and enable knowledge transfer and know-how. Therefore, international cooperation and action on the national level through coastal HUBs aim to define and share a common strategy to foster sustainable exploitation of marine renewable energy. A multi-level approach that connects different stakeholders should help in overcoming existing regulatory, environmental, and social barriers by fostering mutual discussion to find a common interest and strategy.

Above mentioned will be achieved by establishing a multi-level network of Coastal HUBs, which consists of Cross-border HUB and 8 Local Coastal HUBs, one per each included area. Finally, to ensure the durability of project outputs and results, a joint IT-HR Coastal Energy Observatory will be established to serve as a basis for further research activities and business-support decisions. The important project output will be geo-referenced BE potential analysis with gathered data and observations regarding the real potential to exploit wave and thermal energy potential. The geodatabase will be an open tool to ensure the transferability and accuracy of incorporated data. Also, each project partner is expected to carry out necessary activities regarding the selection of the pilot area for which is then the most appropriate technology selected alongside the energy potential estimation. Besides, the expected project results are:

- Joint knowledge framework (regulatory, environmental, spatial planning) on BE potential for included coastal areas
- Improved cooperation and knowledge transfer among the key actors from the established Italian-Croatian Coastal cluster
- Feasibility studies for Coastal Energy projects in target ports and urban coastal areas

1.2. Purpose of the Analysis

This report is done as a part of *Work package 3- Analysis of the potential of integrated Blue Energy production in the Programme area's coasts*, activity *3.4 Blue energy potential analysis*. Under this activity is expected to assess the most suitable technologies for the Adriatic Sea within the identification of pilot areas for preliminary studies. Obtained preliminary studies will be incorporated in an online geodatabase with useful information for the further development of marine renewable energy technologies. Also, it is expected to carry out an analysis regarding the environmental and socio-economic impacts that may arise from the exploitation of BE. This implies the analysis of external opportunities and threats that can affect the development of BE projects in targeted areas.

As it was already mentioned, analysis is divided into two separate reports, starting with this one which includes the BE potential analysis for the predetermined area with the prospect on possible technologies. The second report will investigate the potential more in detail by estimating the potential for the most appropriate technology and selection of several pilot areas. These two reports are closely related and gathered results and knowledge will be used for project deliverables. The first part is in the scope of the deliverable D3.4.1- Preliminary document, while the second report will be used for Energy potential analysis of pilot areas (D3.4.3). Relevant case studies could be used furthermore for online IT-HR Coastal Energy geodatabase (D3.4.2).

1.3. Methodology

The methodology used here is based on predetermine project work package methodology available in deliverable *"D3.1.1 Methodology for the background analysis"* with adjustments appropriate for such Analysis. In each section of the report, a comprehensive picture of the Mediterranean Sea is firstly presented. Since the Adriatic Sea is part of the Mediterranean (MED) and has notable similarities, blue energy potential and technology is firstly discussed on MED scale, and then focused on the national case and selected archipelago area. This way, current trends and achievements in research and development (R&D) are accurately covered and presented with respect for national and micro-locations specifics.

Moreover, up to now, BE potential analysis and opportunities in the marine renewable energy sector were occasionally discussed on the MED level, only with the rough elements of national and micro-locations specifics. Detailed analysis of the Adriatic Sea is done. Therefore, estimation is based on gathered knowledge from a similar case study analysis.

The analysis was carried out in the way presented in Figure 1. Firstly, existing data and information relevant for the exploitation of BE potential were collected, analysed, and systemized. Used data are collected from previous projects and respective deliverables related to exploitation of the BE potential such as MAESTRALE, PELAGOS, and ENERCOAST. To acquire as much as possible information, scientific databases SCOPUS and Web of Science are scanned with the focus on scientific papers that covers technology readiness level and case study analysis for the MED area. Additional literature was used where appropriate and where information from previous projects and scientific literature were insufficient. Once when enough information was acquired, BE potential analysis was carried out considering site specifics and economic perspectives. This implies that reviewed technologies were evaluated with respect for their applicability in the considered environment, considering environmental, technical, and social concerns. More on this is discussed in the following section. Finally, once when analysed technologies and their respective potential was evaluated, the most appropriate technology is selected, and potential pilot areas are proposed.

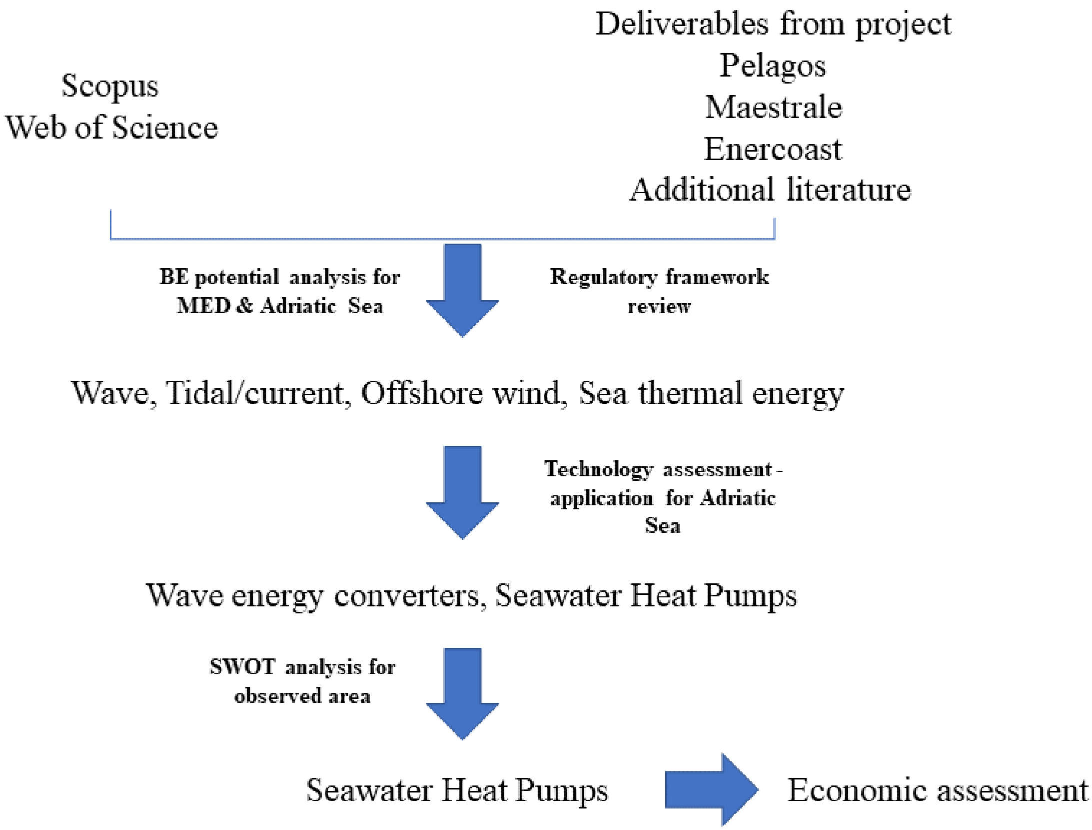


Figure 1 - Methodology used for the BE potential analysis and technology assessment

2. Identification of feasible technologies and pilot areas

This section is dedicated to the BE potential analysis for the selected areas. Firstly, the regulatory framework applicable to blue energy installations is reviewed on an international, national, and regional level. This was later used for SWOT analysis to determine the most appropriate technology and energy source for the pilot areas. The main part of the analysis is dedicated to the blue energy sources analysis on a Mediterranean level, and where possible for the case of the Adriatic Sea. This was supported by the technology assessment where the examples of good practice, which are in line with project objectives, are reviewed. Finally, a SWOT analysis was used to define suitable solutions.

2.1. Regulatory framework review

A regulatory and legislative review is done in a manner where firstly relevant international and EU directives are presented, followed by the national review of relevant Acts and Laws. Finally, additional regional and local regulations are considered and revised since the projects related to energy exploitation must comply with all the mentioned regulations. International directives are briefly presented without additional explanation since they are more related to the strategic orientation of EU policy in both terms, technical advancement, and environmental protection.

2.1.1. Relevant international directives for BE projects

- Convention for Protection of the Mediterranean Sea against pollution- Barcelona Convention 1976
- Action needed to deliver on the potential of ocean energy in European seas and oceans by 2020 and beyond- COM 2014 008 Blue Energy
- Offshore Wind Energy: Action needed to deliver on the Energy Policy Objectives for 2020 and beyond.
- Directive 2000/60/EC: Water Framework
- Directive 2008/56/EC: Marine Strategy Framework
- Directive 2014/89/EU: Marine Spatial Planning

2.1.2.Relevant national regulations: Croatia

In Croatia, there are no specific policies and authorization procedures for building offshore infrastructures for the exploitation of Blue energy. Actual laws regulate the use of renewable energy sources (RES) with only a few references to Blue energy. Several legislation documents exist which are responsible for RES and RES integration into the energy system. The most important national legislation documents related to RES projects are listed below with a brief explanation and relevance for BE projects. Besides presented Acts, often there are several Amendments and support statements that should be considered as well.

Energy Act (Official Gazette 120/12, 14/14, 102/15)

The Act regulates measures for the safe and reliable supply of energy, and its efficient production and use. Acts establish which energy policy and energy development planning are implemented, execution of energy activities, on the market or as public services, and fundamental issues in the implementation of energy activities.

Under Article 3, Point 17 the renewable energy sources are named, and these include renewable non-fossil energy sources (aerothermal, biomass, **sea energy, wind energy,** hydropower, geothermal and hydrothermal energy, gas from landfills, gas plant for wastewater treatment and biogas, solar energy).

Regulation of Energy Activities Act (Official Gazette 120/12)

The Act regulates the establishment and implementation of the regulation system for energy activities, the process of establishment of the body for energy regulation, and other issues of importance for energy regulation.

Electricity Market Act (Official Gazette 22/13, 102/15, 68/18, 52/19)

The Act regulates the manner of performing energy activities in the areas of electricity and the production, transmission, distribution, and supply of electricity and organization of the electricity market.

The Act governs the Energy approval for a new production facility. The production facilities can be built by a legal or private entity if the intended production facility meets the criteria laid down in the procedure for issuing energy approval. The criteria for the procedure for issuing energy approval for the construction of production facilities are public and are based on the principles of objectivity, transparency, and impartiality.

The renewable energy sources and high-efficiency cogeneration Act (Official Gazette 100/15, 123/16, 131/17, 111/18)

The Act regulates the planning and encourages the production and consumption of electricity produced using renewable energy sources and high-efficiency cogeneration. The Act establishes measures to promote the production of electricity using renewable energy sources and high-efficiency cogeneration. The act regulates the issues of construction of plants on state land and governs the implementation system to encourage the production of electricity from renewables and high-efficiency cogeneration. The Act further regulates the keeping of the register of projects, project developers and privileged producers of electricity from renewable energy sources and high-efficiency cogeneration, regulates the issue of international cooperation in the field of renewable energy and other issues of importance.

The Act governs the planning, design, construction, use, maintenance and removal of production facilities and production units that produce electricity from renewable energy sources and high-efficiency cogeneration. The Act stipulates that properly the provisions of the regulations governing the protection of the environment and nature protection and preservation of cultural goods, state aid, spatial planning, construction, electricity market, concession, maritime domain, water management, the pursuit of economic activities, the right ownership and other related rights and the provisions of other regulations.

Under Article 4, Point 11, renewable energy sources are named. These include aerothermal, biomass, energy from bio-liquids, **sea energy**, hydropower, wind energy, geothermal and hydrothermal energy, gas from landfills, gas from wastewater treatment and biogas, solar energy, and a biodegradable fraction of certified waste for energy production in an economically viable manner following the regulations of the administrative area of environmental protection.

Ordinance on the status of privileged electricity producer (Official Gazette 132/13, 81/14, 93/14, 24/15, 99/15, 110/15)

The Ordinance establishes conditions for acquiring the status of privileged electricity producers which may be acquired by a project holder or producer who simultaneously produces electricity and heat, uses waste or renewables for electricity production in an economically viable manner in compliance with environmental protection.

The tariff system for electricity produced from renewable energy sources and Cogeneration (Official Gazette 116/18)

The Tariff System to produce electricity from renewables and cogeneration regulates the right of privileged producers to an incentive price of electricity paid by the market operator.

Power plants using blue energy for power generation are included in the tariff system under the term Other power stations on renewable energy.

Construction Act (Official Gazette 153/13, 20/17, 39/19, 125/19)

The Act regulates the designing, construction, use and maintenance of construction works and the enforcement of administrative and any other procedures relating to it to ensure protection and planning of space following the regulations governing physical planning and providing the essential requirements for construction works and other requirements prescribed for construction works under this Act and regulations adopted on the basis thereof as well as under special regulations.

Physical Planning Act (Official Gazette 153/13, 65/17, 114/18)

The Act regulates the physical planning system aims, principles and subjects of physical planning, spatial monitoring and monitoring in the field of physical planning, spatial planning requirements, adoption of the Spatial Development Strategy of the Republic of Croatia, spatial plans including their development and adoption procedure, implementation of spatial plans, building land development, property postulates of building land, development and supervision.

Spatial planning is a permanent process that includes knowing, verifying, and assessing the possibilities for the use, protection and development of space, development and adoption of spatial plans and monitoring implementation of spatial plans and the situation in space.

The Act regulates the physical planning system according to the Spatial Planning Strategy of the Republic of Croatia, and lower-level spatial plans (county and city spatial plants).

Under Article 3, Point 1, the terms used in this Act are defined as the following:

6. building land means built-up land, developed or for which the spatial plan envisages the building of construction works or the development of public purpose areas;

7. building area is an area defined by the spatial plan on which there are a built-up settlement and area planned for improvement, development, and expansion of a settlement, consisting of the building area of a settlement, detached part of the building area of a settlement and detached part of the building area outside a settlement;

8. infrastructure are municipal, transport, **energy**, water, maritime, communication, electronic communication and other construction works intended for managing other types of manufactured and natural goods;

9. detached part of the building area outside a settlement means an area defined by the **spatial plan** as a spatial unit outside the building area of a settlement planned for all purposes other than residential;

Under Article 6, Point 1, one goal of physical planning is defined as:

2. spatial sustainability regarding the rational use and preservation of spatial capacities on the land, **sea and the seabed**, with the objective of efficient space protection;

Under Part 4. Requirements for spatial planning, Subpart 4.1. Building area and planning outside of the building area of this Act, Article 42 defines the following:

(1) The building area shall be determined by the spatial development plan of a city or municipality and by the Spatial Plan of the City of Zagreb for demarcation of built-up parts of these settlements and areas foreseen for their development from other areas intended for the development of agriculture

and forestry, as well as other activities which, given their intended purpose, could be planned outside of building areas. (3) A detached building area outside of settlement may also be defined with the State plan for spatial development and county spatial plan to implement a project which is of significance to the State or the county.

Article 44, Point 1, states that **building may be planned outside the building area** if it is:

1. infrastructure;

5. areas of economic use of **the maritime domain and beach development**.

Under the Sub-part 4.2. **The protected coastal area** of this Act, Article 45 defines the protected coastal area:

(1) The protected coastal area shall be an area of special state interest.

(2) The protected coastal area shall encompass the area of coastal self-government units.

(3) Planning and use of protected coastal area space shall be performed with limitations in the continental belt and islands 1000 m in width from the shoreline **and the sea belt 300 m in width from the shoreline** (the restricted area) for protection and achieving objectives of sustainable, purposeful, and economically efficient development.

Under Article 48, Point 1, summarizes the projects in a restricted area that are not permitted:

3. the exploitation of wind power for the generation of electricity.

Environmental Protection Act (Official Gazette 80/13)

This Act regulates environmental protection and sustainable development principles, protection of environmental components and protection against environmental burdening, actors in environmental protection, sustainable development and environmental protection documents, environmental protection instruments, environmental monitoring, information system, ensuring access to environmental information, public participation in environmental matters, access to justice, liability for damage, financing and instruments of general environmental policy, administrative and inspection supervision.

Maritime Code (Official Gazette 81/04, 76/07, 146/08, 61/11, 56/13)

This code specifies the maritime and submarine areas of the Republic of Croatia and the legal relationship between them, the safety of navigation in the internal waters and territorial sea of Croatia, protection and preservation of natural marine resources and the marine environment, basic substantive relations in terms of vessels, contractual and other relations on vessels, registration of vessels, limitation of shipowner's liability, enforcement, and insurance on ships.

Under Article 5, the terms used in this Act are defined as the following:

2. maritime object is an object designed to sail (vessel), or facility permanently moored or anchored at sea (vessel), or facility fully or partially buried in the seabed or laid on the seabed (fixed offshore facility).

Under Chapter IV. Exclusive Economic Zone of this Code, Article 32 states the following:

The exclusive economic zone of the Republic of Croatia includes marine areas of the outer limit of the territorial sea seaward to the outer limit of its permitted general international law.

Under Article 33, Point 1 states that in its exclusive economic zone, the Republic of Croatia **shall exercise sovereign rights** for the purpose:

a) exploration and exploitation, conservation, and management of living and non-living natural resources,

b) **energy production using sea, sea currents and winds**.

Maritime demesne and seaports Act (Official Gazette 158/03, 141/06, 38/09, 123/11, 56/16, 98/19)

The Act regulates the legal status of the maritime demesne, deciding the limits thereof, the management and protection of maritime demesne, its use and exploitation, classification of seaports, the port area, establishing the port authorities, port activities and exercising thereof, the construction and use of port superstructure and infrastructure, as well as the essential issues concerning the order in seaports.

Under Article 2, one of the terms used in this Act is defined as follows

5. **Concession** shall mean the right by which a part of the maritime demesne is partly or entirely excluded from general use and conceded to natural and legal persons for special use or commercial exploitation in compliance with spatial plans.

Under Article 19, **the specific use** of the maritime domain is:

2.) building on the maritime domain structures and other infrastructure facilities (roads, railways, water supply, sewage, **energy**, telephone network, etc.), buildings and other facilities for the needs of defence, internal affairs, regulation of rivers and other similar infrastructure facilities.

Under Article 20, it is defined that concession for a maritime domain can be granted for the period between 5-99 years. If the usage of maritime domain is of the county interest then they are authorised for issuing permits. If it is of national importance, then it is under the authority of the Government.

l) Water Resources Law (Official Gazette 153/09,119/15, 120/16, 127/17, 66/19)

This Law regulates the legal status of water, water resources and water structures, quality management and quantity of water, protection against harmful effects of water, detailed melioration drainage and irrigation, public water supply and public drainage, special activities for water management, institutional setup of performing these activities and other issues related to water and water resources. The regulations set in this law need to be met by the **blue energy** structures.

As can be seen from the regulation overview, a particular focus for the development of energy projects, especially those related to blue energy, is the Physical Planning Act (Official Gazette 153/13, 65/17, 114/18). Even though the Act does not explicitly mark blue energy installations, it presents the rules for the usage of the maritime domain, which is crucial when it comes to blue energy projects. If the installation of a bigger capacity is planned, an investor must follow The Renewable Energy Sources and High-Efficiency Cogeneration Act (Official Gazette 100/15, 123/16, 131/17, 111/18) and respective Laws regarding the status of privileged electricity producer. Moreover, for the BE projects, it is also essential to be in ordinance with the Maritime Law and Water Resources Law and to be incorporated in spatial planning of the Croatian energy system (Figure 2). The former one is important to obtain the concession for the usage of water, while the bottom one is applicable if there is a need for the physical incorporation of distribution infrastructure to the national grid. Also, since the maritime domain presents a sensitive environment liable to external factors, the investor occasionally must obtain Environmental Impact Assessment. This is used as a piece of evidence that planned actions would not cause severe and long-time negative impacts regarding the maritime inhabitants and coastal landscape.

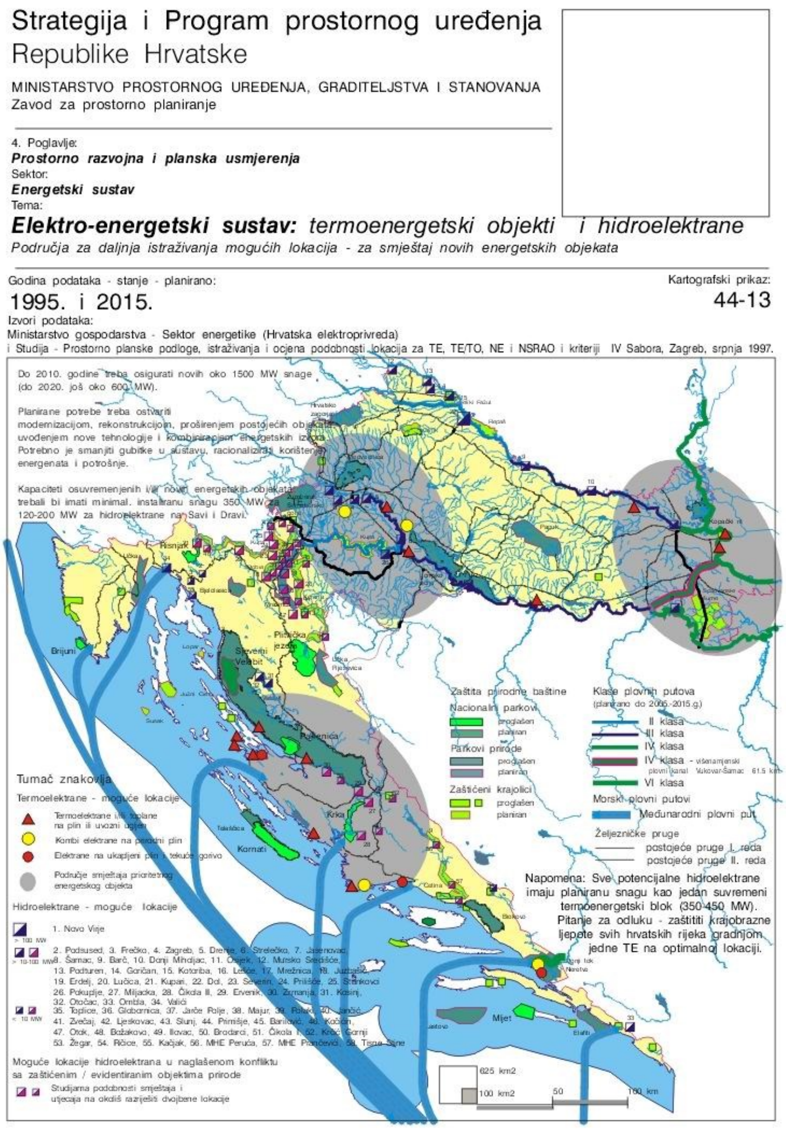


Figure 2 - Croatian energy system-spatial plan

In the case of heat pumps installation, a concession for water usage must be granted as well as the particular focus should be given to the usage of the maritime domain for infrastructural needs. In the case of Croatia, direct usage of seawater as a cooling medium for heat pumps is often prohibited or complicated. Therefore, it requires alternative solutions. One is the drilling of dwellings close to the utilisation point and fetches for brackish water. This causes additional investment costs, which will be elaborated in the following subsections. Besides the national level, regional and local regulation must be considered during the planning phase as well. Since up to now, there are no projects related to BE installations procedure for obtaining necessary permissions is quite unclear and complicated. This is especially applicable for spatial planning when there is not clear who oversees issuing permits. This misunderstanding often arises between local/regional and national authorities, and it complicates the overall procedure and causes significant delays in project implementation.

2.1.3 Relevant national regulations: Italy

An overarching problem of the Italian regulatory framework – at both national and regional levels – is that in general national laws and regulations do not explicitly mention or consider Blue Energy systems.

Therefore, permitting procedures must be inferred based on the specific characteristics of the installations (whether onshore or offshore, submerged or not, etc.) and, in parallel, with the features of the chosen location (port, littoral, Natura 2000 site, etc.).

The only exception is represented by the Government Circular by the Ministry of Infrastructure and Transports n. 40 of 5/1/2012 - Set of norms and regulations concerning authorization procedures for offshore renewable energy production plants. This provides guidelines based on previous regulations (D.lgs. 387/2003, Law 244/2007, art. 36 of Navigation Code) for simplifying authorization procedures for the construction of offshore renewable energy plants.

Such authorizations imply interventions by different government bodies such as:

- the Maritime Authority (i.e., Port Authority, Maritime Directorate, or Ministry of Infrastructure and Transports, depending on the duration of the state concession needed), for the state concession over seawaters;
- the Port Authority, for the state concession over coastal areas where the cables reach the mainland;
- the Ministry of Infrastructure and Transports, for the proper authorization;

- the Ministry of Economic Development and the Ministry of the Environment, which must give their opinion over the above authorization;
- the Police and the Maritime Authority, for additional provisions concerning the safety of navigation;
- the Ministry of the Environment, for the Environmental Impact Assessment, if necessary;
- the grid operator, for the price quotation concerning the works for the connection to the grid;
- the Region, the Province, and the involved municipalities, for the matters concerning spatial planning, restrictions over cultural and environmental assets, and landslide safety;
- other bodies such as the Public Works Office, public health institutions, Superintendent's, military bodies, firemen, natural parks, etc., if applicable.

According to the Circular, the authorization request must be submitted to the Ministry of Infrastructure and Transport (General Directorate for Ports), and to the Ministry of Economic Development (Department of Energy – General Directorate for nuclear energy, renewable energies, and energy efficiency – Division III; General Directorate for mining and energy resources – Division I; and the Local Inspectorate of the Department for Communications).

The request must contain the preliminary project (including the price quotation by the grid operator for the connection to the grid, and the design for the connection to the grid, previously approved by the grid operator) and a copy of the application submitted for the state concession. The preliminary project must also identify, if applicable, the areas subject to expropriation, and the necessary buffer zones.

The request for the state concession must be submitted to the Ministry of Infrastructure and Transport, or the competent Maritime Directorate in case the concession is between 4 and 15 years of duration.

The circular also aims at simplifying the authorization procedures. In particular, it proposes that the Port Authority can directly acquire the technical opinions of all other relevant bodies such as the Public Works Office, public health institutions, Superintendent's etc. within the same procedure. After having acquired these opinions, the competent Maritime Authority invites the proponent to submit the definitive project, which must be submitted to the same Maritime Authority, the Ministry of Infrastructure and Transport, the Ministry of Economic Development, the Ministry for the

Environment (together with the Environmental Impact Study, if applicable), and to other bodies in case they have specifically requested it.

To issue the authorization, the Ministry of Infrastructure and Transports calls for a “conferenza dei servizi” including the Ministry of Economic Development, the Ministry for the Environment, the Port Authority, the relevant municipalities, the grid operator, and other bodies, if applicable.

The authorization is issued within 15 days from the issuing of the state concession.

Though the Circular is useful for understanding and simplifying a complex matter involving a considerable number of public authorities, the procedure described is not always clear; moreover, it regards (even if it is not clearly stated) offshore wind farms mainly.

However, some important issues are highlighted, mainly regarding the assessment of environmental impacts, the authorization of electric activities, and the permitting of underwater works.

Environmental impact assessment

New installations shall undergo a screening procedure for the Environmental Impact Assessment, in compliance with the national Legislative Decree nr. 152/2006.

This law regulates the procedure of Environmental Impact Assessment, transposing the dedicated EU Directives 2011/92/EU e 2014/52/EU. Projects are categorized according to whether they are controlled by the State or by the Regions, and whether they are subject to EIA screening or the complete EIA procedure. Projects regarding blue energy, or related to blue energy infrastructure, are categorized as follows:

- projects controlled by the State and directly subject to EIA procedure: activities of research and exploitation of marine geothermal resources;
- projects controlled by the Regions and subject to EIA screening:
  - non-thermal industrial plants for the production of energy, steam and hot water with power above 1 MW;
  - coastal works for protection against erosion and works aimed at modifying the coastal line (dykes, jetties and other coastal defence works).

According to the above definitions, most blue energy projects of the type addressed by COASTENERGY would be subject to EIA screening and undergo a procedure managed by regional offices in charge of environmental assessment.

Additional impact assessment may be necessary for installations affecting Natura2000 sites.

Authorizations

It is a prerogative of the national government to establish the basic principles of national energy production and distribution through national legislative acts and that of the regions to exercise their legislative power within the binding framework of these principles, as explicitly determined by the national government.

Further constraints are set by the EU directives and the national government, which has exclusive competence on transversal topics, such as the protection of the environment and competition. Regions are responsible for regulatory and administrative functions which are not explicitly attributed to local authorities or the national government.

To produce offshore energy from renewable sources, Legislative Decree 387/2003 is the main reference, in particular art. 12 and subsequent amendments. By the current division of functions, each Region has proceeded to legislate and regulate energy through specific acts, which are listed, together with the relevant national legislation, in Appendix 4.2.1. of the national action plan.

Blue Energy installations based on wave energy conversion will therefore need a regional permit for electrical activities. Moreover, for connecting the installations to the national grid, a connection request must be submitted to Terna – the management body of the Italian transmission network.

A useful reference document is the "Single text" to produce electric energy – a collection of regulations concerning the production of electric energy (with particular reference to renewable energy), issued by ARERA, the national authority regulating the electric energy, natural gas, water, waste, and district heating sectors. It provides a comprehensive recap of information concerning all aspects of the production of electric energy: connection to the grid; methods for measuring the energy produced, withdrawn from the grid, and consumed; transmission and distribution of energy; coordination of energy input; modalities for transferring the energy produced to the grid; subsidies, etc.

Underwater works

Blue Energy installations near and offshore may require underwater works, which must be authorized by the Coast Guard as per Law 24/03/2012, nr. 27, art. 16, subsection 2.

This subsection provides that underwater works for mining explorations, placement of platforms, inspection and maintenance of infrastructure, and other related works must comply with the UNI 11366 norm ("Health and safety in diving and hyperbaric professional activities – Operational procedures").

Support for the development of ocean energy

In Italy, the growing interest in the exploitation of wave and tide technology to produce clean and renewable energy can be recognized both in research and development activities carried out by public and private actors, and in the government's intervention (incentives for ocean renewable energies have been set in the Italian Action Plan for renewable energies).

Research and development

The main actors involved in research and development in this field are universities, spin-offs, SMEs, and large enterprises; thanks to their efforts, Italy is at the forefront of research for the development and testing of prototypes and pre-commercial devices for the conversion of ocean energy.

This is confirmed by the number of international partnerships in which Italian actors are actively involved.

Several Italian Universities and CNR-INSEAN are partners in the largest projects co-financed by the EU in the field of ocean energy technology.

Italy's leading role in the blue energy sector was recently recognized by the Corporación de Fomento de la Producción (CORFO), the economic development organization appointed by the Chilean government; Enel Green Power (EGP) from Italy and DCNS from France has been selected to create an innovative global centre of excellence in R&D in the marine energy sector in Chile, called the Marine Energy Research and Innovation Center (MERIC). The research and development work applied by MERIC will focus on key marine renewable energy sources such as tidal energy and wave energy.

Market incentives

Italy has given priority and encouraged the deployment of renewable energies through the adoption of a series of rules and regulations that have transposed the EU Directive 2009/28/EC into Italian national legislation. The principles and objectives of this regulatory framework are summarized in the 2010 National Renewable Energy Action Plan, followed in 2013 by the National Energy Strategy, which was recently updated (NES 2017). The Italian legislative acts are thereby classified concerning their compliance with specific indications of the transposed Directive, according to the following categories:

- measures under articles 13, 14, 16 and 17-21 of the aforementioned directives (administrative procedures, regulations and codes);
- measures for the production of electricity and from renewable sources;
- measures in favour of the use of renewable energies in heating/cooling systems;
- measures in favour of the use of renewable energies in the transport sector;
- specific measures aimed at promoting the energy use of biomass;
- statistical transfers between the Member States and joint projects between the Member States and the Member States and third countries.

The latest indications and regulatory measures for the operational implementation of the national strategy and plan have been issued with Ministerial Decree 23/6/2016, updating the support regime previously regulated by Ministerial Decree of 6 July 2012.

The Decree identifies four different ways of accessing incentives: direct access, registers for new or upgraded power plants, and auction offers (Dutch auctions). The decree defines the criteria for accessing registers and auctions and establishes specific limits for the annual capacity eligible for incentives. These limits are set differently for each type of renewable energy source and for all the different ways of accessing incentives (registers or auction offers). In general, the Decree grants a fixed tariff plus, in some cases, a specific premium, to incentivize the net electricity fed into the network. The flat rate varies according to the source, technology and capacity range considered. Power plants with a capacity higher than 500 kW can receive the incentive (fixed rate minus the hourly zonal electricity price, plus premiums if applicable). Power plants with a capacity lower than 500 kW can alternatively receive an injection tariff consisting of the fixed tariff plus, in some cases, a specific bonus.

Directive 2014/89/EU on maritime spatial planning is also relevant to the Blue Energy sector, as it establishes a framework for the implementation of maritime spatial planning and integrated coastal management by the Member States, able to regulate public funding for research projects of general interest in the electricity sector.

Moreover, the Italian Ministry of Education, University and Research has launched two calls for proposals to grant funding for strategic research activities, including the blue energy sector

2.1.4 Regional and local regulations applicable to the defined areas: Croatia

As mentioned above, regional, and local regulations must be obeyed when planning energy-related projects. The case of the Cres-Lošinj archipelago is related to Primorsko Goranska County (regional authority) and Municipality of Cres and Mali Lošinj (local authorities) plans and regulations. For the case of a project with higher significance, as well as for the offshore instalments, County spatial Plan for energy-related infrastructure (Figure 3) and Plan for environmental preservation (Figure 4) must be considered. Primorsko Goranska County Physical Plans are available online at the following address: https://zavod.pgz.hr/planovi_i_izvjesca/Prostorni_plan_PGZ. General information is given regarding the implementation of plans, which are supported by maps and web GIS platforms with a spatial plan. Besides, local authorities should be consulted to incorporate energy-related projects in local spatial plans. For the City of Cres, this information is available on the following link https://www.cres.hr/urbanisticki-planovi and for the City of Mali Lošinj https://www.mali-losinj.hr/prostorni-plan-uredenja-grada-mali-losinj-procisceni-tekst/.

Figure 3 - Primorsko Goranska County Spatial plan – Plan for energy-related infrastructure [1]

Figure 4 - Primorsko Goranska County Spatial plan – Plan of environmental preservation [2]

Local authorities are also in charge of giving concessions on the maritime domain for projects and facilities of local importance. Procedure for obtaining *Concession for special use of the maritime domain* is regulated in the Maritime domain and Seaport Act (Official Gazette 158/03, 141/06, 38/09, 123/11, 56/16, 98/19). Also, local authorities oversee issuing permission for the usage of seawater through wells. Moreover, local authorities are prescribing the fee for the seawater usage independently for each project. This often complicates the procedure and requires a lot of communication with authorities which might cause delays in project implementation.

2.1.5 Regional and local regulations applicable to the defined areas: Italy

In Italy, regional-level administrations have wide legislative powers, and their competencies range from territorial governance to environmental assessment, to spatial and energy planning. Therefore, regional regulations can have a significant potential impact on the development of Blue Energy.

However, provisions of regional regulations are different in the various regions, and their relevance for the COASTENERGY project varies greatly, also according to the implementation status and the level of detail of the related planning instruments, to the interactions with other levels of governance and with other public bodies (Municipalities, Port Authorities, etc.), and so on. Moreover, some Italian regions are under a special statute, assigning them additional powers; Friuli Venezia Giulia (FVG) is one of these regions.

The main types of instruments that must be analysed and taken into account when planning Blue Energy initiatives in an Italian region are the following:

- Regional laws on coast protection (i.e., the Regional Laws 17/2015 of Apulia, and 15/2004 of Marche), regulating the exercise of administrative functions related to the management of the maritime State property and the territorial sea areas devolved by the State under article 117 of the Constitution, and defining responsibilities and tasks of the Regional Government and the Municipalities;
- Regional and Municipal coastal plans (i.e., the Regional Coastal Plan approved in Apulia with Regional Council Deliberation no. 2273 of 13/10/2011, or the Integrated Coastal Zone Management Plan of the Marche region);

- Regional Territorial Landscape Plans under art. 135 and 143 of Legislative Decree n. 42/2004, "Code of cultural heritage and landscape" (i.e., Apulia's Plan approved with Regional Council Deliberation no. 176 of 16/2/2015; FVG's Plan approved in 2018 by Decree of the President of the Region Nr. 0111; Marche's Plan, currently under revision);
- Regional Ports Plan, when relevant (i.e., the one approved in the Marche Region in 2010);
- Regional laws on urban and spatial planning (i.e., the Regional Law n. 34/1992 of the Marche Region), notably when onshore installations are foreseen;
- Regional Plan for the Protection of the waters (where available), like the one, approved in 2018 in Friuli Venezia Giulia;
- Regional laws defining responsibilities and tasks of regional and local governments in the energy sector (i.e., the Regional Law n. 10/1999 of Marche Region);
- Regional Energy Plans, when relevant;
- Provisions for the environmental protection of regional reserves (both marine and terrestrial).

Most regional-level plans do not include provisions on Blue Energy installations. There are, though, some exceptions, for example:

- Apulia's Regional Territorial Landscape Plan, stating that "the location of off-shore plants will not be allowed in marine Natura 2000 sites and protected marine areas, nor in the presence of Posidonia meadows and marine biocoenoses of conservation interest"; that "the use of floating structures must be privileged"; and that "investigations aimed at ascertaining the interference of submarine pipelines with existing species must be carried out, adopting laying and landing techniques aimed at minimizing the impact".
- The Marche Region's Integrated Coastal Zone Management Plan, which allows – in limited coastal sections – the construction of "experimental" coastal protection structures incorporating pilot installations for the exploitation of sea energy, either replacing or integrating existing structures. The Plan also considers the installation of wave energy systems as a viable option to reduce coastal erosion.

Moreover, it is important to underline that regional authorities are usually in charge of:

- managing environmental assessment procedures regarding non-thermal industrial plants for the production of energy with power above 1 MW, and coastal works for protection against erosion and works aimed at modifying the coastal line (see 2.1.2);

- issuing permits for electrical activities (see 2.1.2);
- permitting of structural interventions related to coastal protection, which must also undergo the EIA screening and be approved by the Civil Engineering Department (that has jurisdiction on works interfering with the hydraulic balance of littorals);

regulating the construction and rehabilitation of ports of regional importance (also providing guidelines for the design of maritime works within and outside the ports) through a Regional Ports Plan, which is then implemented through the single ports' Master plans. The Region is also in charge of administrative procedures related to the design and implementation of the interventions of construction and rehabilitation of regional ports, and the concessions of the maritime domain for purposes other than energy supply. Moreover, the Region can issue an opinion on the conformity of projects of port structures with the Regional Ports Plan

2.2 Blue energy potential analysis

Blue energy potential analysis is carried out for both the Mediterranean and the Adriatic Sea. Up to now, the majority of BE project and analysis is done on the MED level, while the potential analysis for the Adriatic Sea with precise measurements and calculations are seldom. For this reason, when evaluating the BE potential for the case of the Adriatic Sea, often the literature and analysis for the MED case are used. Since the available data covers the Adriatic Sea and coast at a satisfactorily level, estimations can be carried quite precisely for preliminary analysis. In this report, the following marine renewable energy (MRE) sources are evaluated: surface waves, tidal and offshore wind energy. Additionally, the perspective for thermal energy utilised by seawater heat pumps is given, as commercially viable technology already deployed on several locations alongside the Croatian coast. Since the project aims to foster the installation of BE devices in ports and coastal urban areas, analysis is focused on wave energy, and heat pumps potential, while the rest of MRE are briefly discussed.

Marine renewable energy potential in the Mediterranean Sea is poorly used. Up to now, there are few testing projects for offshore wind, while the rest of MRE technology is in the development phase. When it comes to the Adriatic Sea, besides seawater heat pumps installations, there is no other project related to any form of BE. Even though, wave, offshore wind and tidal energy potentials are reviewed as promising energy sources that may arise in the future.

The analysis of the blue energy potential related to the COASTENERGY project – which aims to produce energy from urban coastal areas and port structures on the Italian and Croatian shores of the Adriatic Sea – will be focused on wave energy potential and thermal energy potential.

Although offshore wind, tidal and current potential is also part of the blue energy sector, they will not be considered in this report for two main reasons:

- the Adriatic Sea, being a closed basin, has very low tidal excursions and currents with little potential;
- wind farms are usually located offshore and therefore exceed the scope of the COASTENERGY project, which rather focuses on onshore and near-shore installations.

Certainly, before moving on to the analysis of energy potentials, it would be useful to understand the bathymetry of the Adriatic, considering that all marine energy potentials depend precisely on the morphology of the seabed and its depths.

The Adriatic Sea develops along an NW-SE direction, between the Italian and the Balkan peninsulas. Its length is approximately 800 km, and its width is 150 km. The general progression of depths is gentler on the Italian coasts and steeper and more irregular on the Balkan side. The only communication with the Ionian Sea, via the Otranto channel, opens on the SE side.

The Adriatic can be divided into three parts, with different bathymetries:

- Northern Adriatic: it extends from the Gulf of Venice and Trieste to the Ancona-Zara alignment. It also includes the recess of Kvarner, particularly rich in islands. Here the bathymetry is generally not very accentuated and gently slopes towards the central part of the sea;
- Central Adriatic: it extends from the Ancona-Zara alignment to the Gargano-Lastovo alignment. The most important morphological feature in this part of the basin is the presence of a depressed area, called the Meso-Adriatic Depression, or Jukala pit. It includes three small basins with maximum depths in the order of 250-300 m and is oriented along a NE-SW direction. Generally, the bathymetry adapts to these formations and the jagged characteristics of the Balkan coast;

- Southern Adriatic: this part of the Adriatic extends from the Gargano-Lastovo alignment to a threshold placed at the latitude of Otranto. In this area, the bathymetry has a sudden drop, down to 3940 m, interrupted only by submarine reliefs that make it rise between 800-1000 m (Monte Dauno off Bari).

Figure 5 - Bathymetry of the Adriatic Sea

2.2.1 Wave energy potential

Wave energy potential is widely investigated on a global level since the 1970s. Nevertheless, for the Mediterranean case, up to the 2010s interest in harnessing the potential of surface waves was weak. Lately, the opposite trend is noticed, and wave energy is getting momentum in terms of potential assessment since there are several ongoing site measurements. Wave energy potential P [W/m] is evaluated using the following equation:

$$P = \frac{\rho g^2}{64\pi} H_{mo}^2 T_e$$

Where ρ is seawater density [1025 kg/m^3], g is the gravity acceleration constant [9.81 m/s^2], H_{mo} and T_e are the significant wave height and the wave period, respectively, defined from the -1 and zero-th order spectral moments. As it is clear, significant wave height and the wave period are the most important wave parameters for the energy potential assessment. There are several advantages of using wave energy, listed below:

- Waves have the highest energy density among RES
- Energy dissipation is relatively small for long distances of wave propagation
- Wave energy is more persistent, even though express season variability

Notes on the method

For the analysis of the energy potential of the wave motion, it is necessary to take into account the diversity of the climatic factors (wind, pressure, etc.) influencing the generation of waves, the waves' fetch, and the morphological variability of the seabed that changes the propagation of the wave motion, and the characteristics of the waves that spread to the coasts.

From a theoretical point of view, during the studies on the evaluation of the wave energy potential of the wave motion off the Italian coast, some variations were proposed to the definition of the gross energy flow per unit of wavelength. The differences focus mainly on the necessary approximations and the interpretation of the amplitude of the wave spectra.

Some authors apply the definition used in the "Wave Data Catalogue for Resource Assessment in IEA-OES Member Countries" (2009) published by the Ocean Energy System – International Energy Agency (OES-IEA).

Mork et al. [3] carried out the wave energy assessment on a global level using the default calibrated wave database contained in the standard WorldWaves package. The used data are for ten years from 1997-2006 at 6-hour intervals and consist of the operational ECMWF WAM model. The global gross resource was estimated to be about 3.5 TW, excluding the area where potential is below 5 kW/m, the net resource is about 3 TW. In the case of the Mediterranean Sea, the potential is quite low, notably if the areas with power potential lower than 5 kW/m are excluded from the analysis. This is because MED is a semi-closed sea where waves are prevented from travelling a long distance without a significant dissipation of energy. The estimated potential for MED is about 37 GW and the highest annual wave energy potential is depicted in the area between Sardinia and Balearic Islands (~9.4 kW/m). For the Adriatic Sea estimated potential is even lower, significantly below 5 kW/m. This is because waves, which are limited in their propagation, must pass through the Strait of Otranto, dissipating a huge amount of energy. Optimal conditions for harnessing the wave energy potential are estimated to be between 1.5-5.5 m for H_{mo} and 7-14 s for T_e. Figure 6 presents annual net coastal power potential worldwide for locations with at least 5 kW/m.

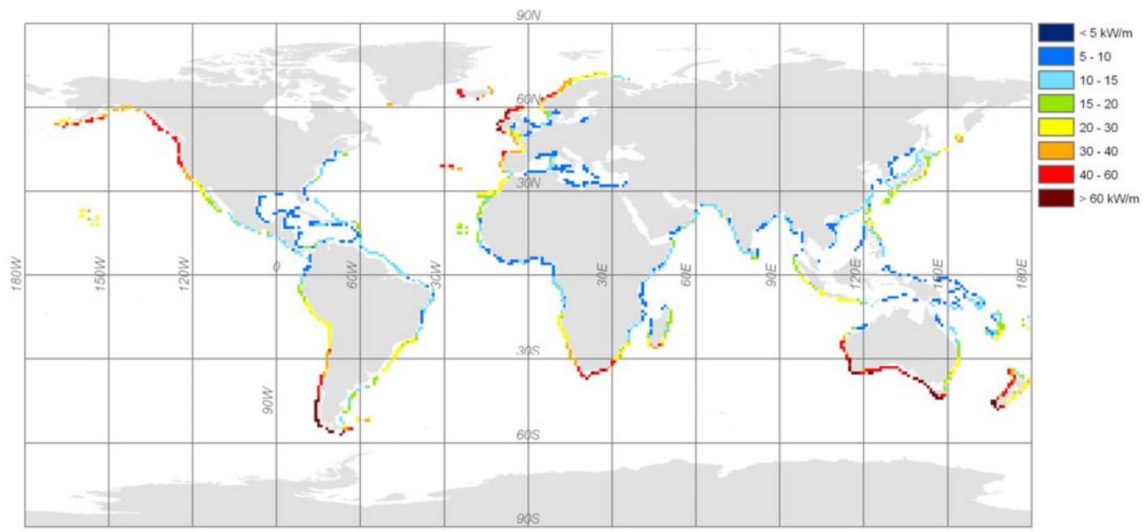


Figure 6 - Coastal wave energy potential worldwide [3]

Monteforte et al. [5] assessed wave energy potential in Sicily by using real data obtained from buoy measurements. Measurements were collected in a period from 8 to 22 years, therefore representing a reliable source of information for precise determination of energy potential. The used model was validated by comparing calculated significant wave heights, with significant wave heights estimated by ECMWF ERA-INTERIM. In particular, the comparison was carried out in 9 ECMWF nodes within the computational domain. The analysis showed that estimated production for the Sicilian coast might be around 9 kW/m in the best-case scenario during the winter period (December, January) when higher wave heights are observed. In general, for a minimum power output of at least 2 kW/m, significant wave height should be H_{mo}>1m, with a wave period of at least T_e>4s. Also, the study presents various limitation that affects wave energy production. Even though waves are not expressing significant variability in day-to-day analysis, a strong seasonal variance is noticed, ~50%. Besides, load factors during the majority of the year are comparably low, especially if technology designed for Atlantic cost is deployed. While the potential for most of the MED sea is around 5 kW/m, for the Atlantic coast and northern Europe locations this is between 10-50 kW/m. As a potential advantage, it is mentioned that wave converters can be incorporated into coastal infrastructure or offshore platforms since they offer hot spots for energy concentration as well as the need for shorter transmission cables. Finally, WECs might serve as artificial reefs for marine inhabitants reducing the negative environmental impact, but this issue requires additional investigations.

Bozzi et al. [6] investigated the potential for implementation of wave energy resources in island environments. Since the islands are geographically isolated and extremely dependent on energy imports, the usage of renewable locally available resources might be beneficial in multiple ways. Measurements were taken for both sides of Italian coasts, with a focus on Sicily and Sardinia as the most prominent locations. For the Adriatic coast, the estimated energy potential was ~2 kW/m, which was accompanied by a strong seasonal variability. Power output, as expected, was the highest during the winter and lowest during the summer periods. Also, research showed that for MED and Adriatic Seas, a load factor of deployed devices would be below 10% for the most time of the year. More than 75% of the time, the load factor is about one order of magnitude of their optimal rating, while in the best-case scenario, around 10% of the time, devices will have a load factor between 20-40%. This couple, with above mentioned seasonal variability, which is between 40-60%, makes WECs cost-ineffective solutions for monitored conditions. Nevertheless, downsizing of devices that are designed for more extreme conditions might be beneficial in both terms, capital investment and annual power output. Moreover, downsizing reduced the seasonal variation by about 20%, simultaneously increasing load factors between 10-15%, depending on the device type and location.

Figure 7 presents the calculated annual coefficient of variation (COV) for energy production from wave energy sources for the case of the Adriatic coast.

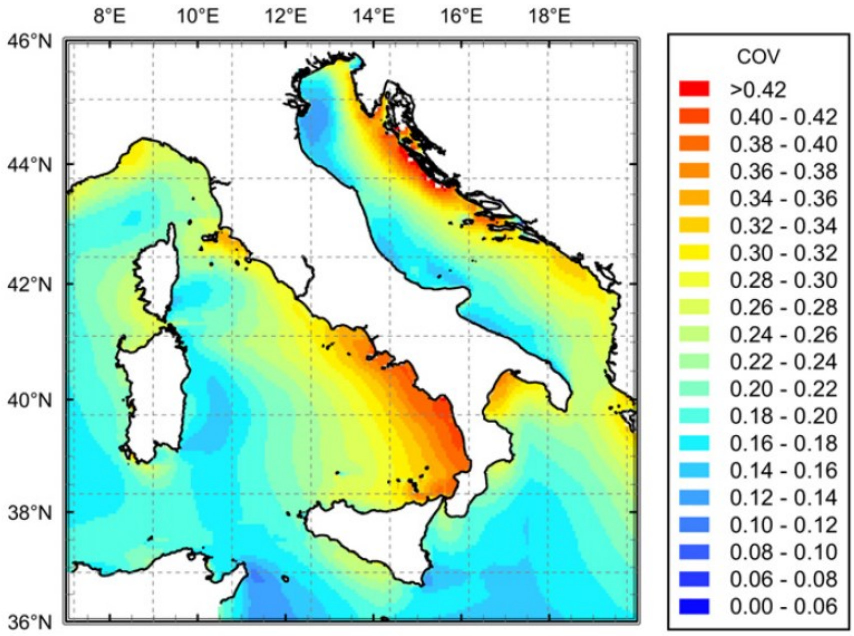


Figure 7 - Calculated COV for the Adriatic coast

Wave energy potential in the Mediterranean

Compared to open seas or oceanic coasts, the Mediterranean Sea is a closed basin with a milder wave climate. For this reason, the fetches (that is, the length of water over which a given wind blows) therein have reduced extension and the waves have limited characteristics and relatively lower wave power.

In fact, for the oceanic coasts, average power varies in a range between 7 kW/m for the southern Danish coasts up to 150 kW/m of the Irish Atlantic coast (Vicinanza et al. 2011).

Figure 8 presents the annual wave energy potential for the Mediterranean Sea basin with the dominant wave's directions.

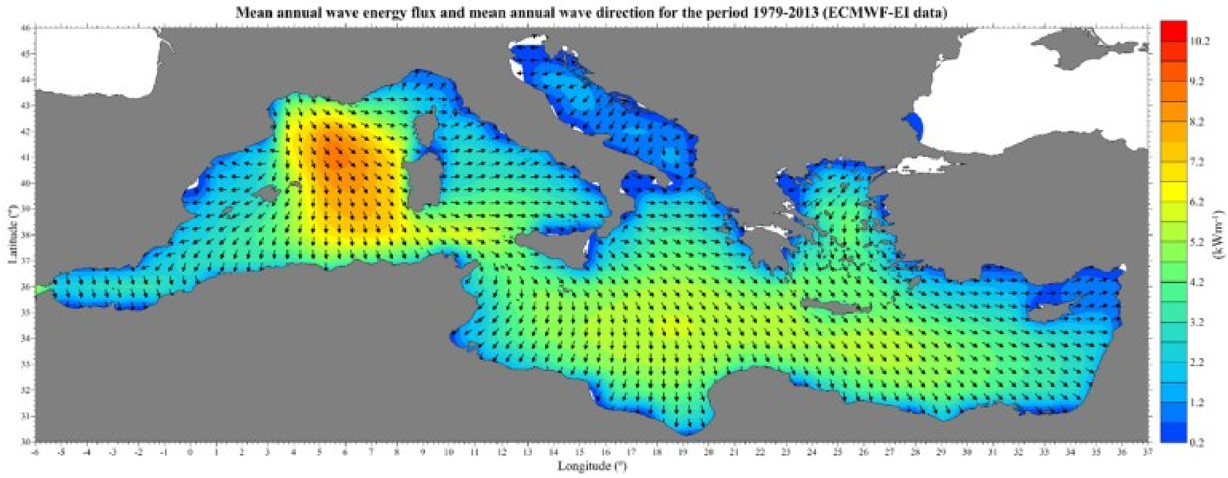


Figure 8 - Wave energy potential for the Mediterranean [4]

For the Mediterranean, the first mapping carried out during the MEDATLAS (2004) project with a spatial resolution of about 50 km, showed offshore wave potentials in the range between 0.75 kW/m in the northern area of the Adriatic Sea and 14.75 kW/m in the western area of Sardinia and Corsica islands.

Subsequently, other authors calculated the potential again using more complete historical data series.

For example, for the area with the greatest power flow (that of the western Mediterranean between the west coasts of Sardinia and Corsica and the Balearic Islands), processing the waveform data recorded by the buoys between 2001 and 2010 in that stretch of sea, the calculated potentials exceed 15kW/m (Liberti et al., 2013), while for the northern Adriatic Sea the quantity is slightly higher than 1kW/m.

By using data collected in a wider period (from 1979 to 2013) and adding corrections, Besio et al. 2016 revised these estimates bringing the potential for the western coasts of Sardinia and Corsica to 20 kW/m.

However, these data refer to waves recorded in the offshore area, which will therefore suffer damping of power during their propagation towards the coastline.

The reduction in the power of the waves depends mainly on their interaction with the seabed and the direction of propagation, therefore on the angle of incidence with the coast and not on the distance of the coast from the wave detection point.

Also, the wave data detected by the buoys can lead to an incorrect calculation of the potential in the near-shore/coastline area, since these data are not “filtered”. When calculating the average wave power, it is more appropriate to subtract from the registered waves those moving from the coast towards the open sea, which has reduced fetch and less time to increase their height and period. In this way, the average wave power increases and therefore results higher than expected.

These observations were confirmed by Vicinanza et al. (2013), who analyzed the difference in offshore and near-shore potentials, identifying seven sites with different geological/geographical characteristics in the North-West portion of Sardinia.

The result of this study showed that, with an offshore wave potential of 10 MW/m/y, the transformations, and the effects that the waves undergo while propagating to the coastline lead to a reduction of their power. The effects of shoaling, geometric refraction, diffraction, and reflection along with energy loss due to white capping, bottom friction and wave breaking can significantly modify the local wave field; in three sites with the higher shoreline/nearshore energy potential, the model showed a decrease in energy of about 35%, in two of 50% and other two even a 70% reduction compared to the potential recorded by the offshore wave buoy.

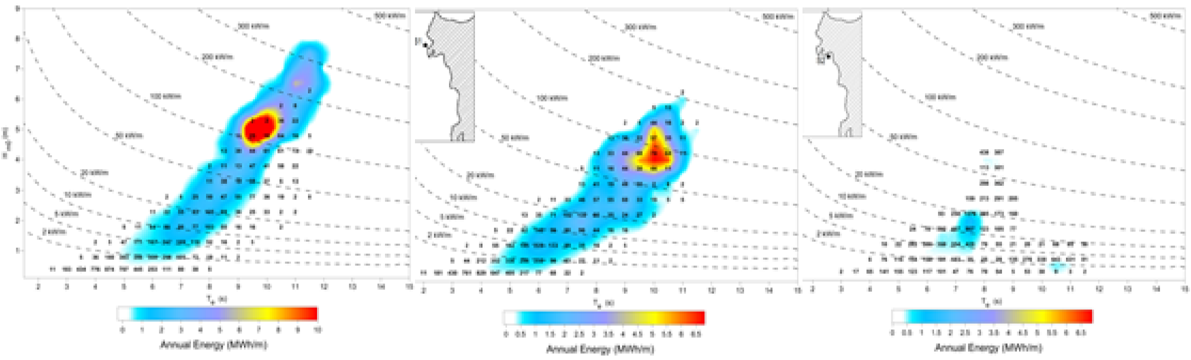


Figure 9 - Difference between offshore and nearshore wave energy.

Liberti et al. [7] carried out a detailed wave energy potential assessment for the Italian case, evaluating the potential for both Italian coasts. From the study it is visible that wave potential for the Adriatic Sea is low, averaging between 2 kW/m for southern parts, and around 0.5 kW/m for the northern part. Since the Cres-Lošinj archipelago is in the northern part of Adriatic, it can be stated that the potential for wave energy generation is extremely low, implying that there is no economic background for such investment. Besides, when seasonal variability is considered, it can be seen that the vast majority of the year, energy flux is below 1 kW/m, and only significant production can be expected during the winter months (December, January, February). But even in these months, production above 2 kW/m is not expected. Figure 10 depicts the seasonal energy flux for wave energy potential at the Mediterranean Sea.

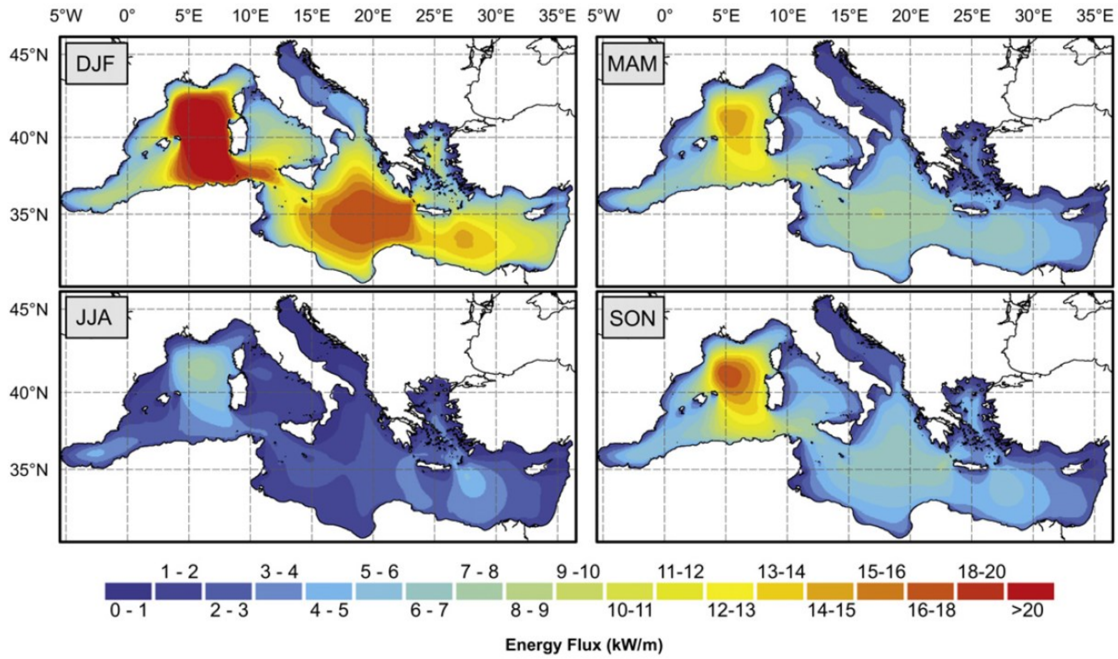


Figure 10 - Seasonal variability of energy flux for wave energy source

Wave energy potential in the Adriatic Sea

The Adriatic Sea extends over an area of around 105 km^2, enclosed by the Dinaric Alps on the East, by the Apennines chain on the West, by the eastern Alps and Venetian plain on the North and by the Otranto channel on the South. Such a configuration makes the basin prone to the channelling of wind.

It is common to divide the Adriatic basin into three sub-areas, mainly according to the bathymetric differences (Orlic et al., 1992): the northern (which comprises the Gulf of Trieste, the Venice lagoon, and the Po delta down to the Conero promontory), the central and the southern one (where water masses can exit towards the Ionian Sea).

The northern area is shallow, with an average depth lower than fifty meters, whereas the central one starts deepening until reaching the Central Adriatic Pit (Jabuka Pit, with a depth of 270 m), and the southern area is characterized by the well-known South Adriatic Pit (SAP), which reaches a depth of 1,200 m and is a key-structure for the whole Adriatic Seawater circulation.

The shape of the basin, its narrowness, and enclosing borders induce specific ocean dynamic responses to external stresses like a superposition of seiches, enhancing tides and gale surges (Lionello et al., 2012). The wind fetch can be very large for south-easterly wind and lower but still important for north-easterly and south-westerly ones leading to the high value of momentum exchange between airflow and water body in terms of Significant Wave Height (SWH) offshore and to regular occurrences of coastal storm surges (better known as *'acqua alta'*).

Moreover, the great number of islands and narrow peninsulas latitudinally stretched on the eastern seaside favours the development of local turbulence, funnelling, rotors, and gustiness. Another key factor is the changeable water runoff of several rivers (mainly Po, Timavo, Piave and the minor ones flowing from the Dinaric Alps and Karstic springs), whose water is fresh, lightly salted, rich in organic compounds, and deeply affects the seawater properties.

Finally, the thermal response of the water mass is faster because of the shallowness.

As regards the orography surrounding the basin, while the Dinaric Alps steepen approaching the Balkan coastline (especially in their northern section, slightly less in the southern section), the Apennines raise more softly. The mountain chains belonging to Dinaric Alps closer to the sea show a distinct sequence of gaps and peaks, the latter ones standing all below 1,800 m in height. This distinctive feature is crucial for wind propagation across the sea. The Apennines, on the contrary, are sharper, 1,500 km long and, on average, attain higher altitudes with several peaks above 2,000 m (e.g., Monte Cimone 2165 m, Monte Terminillo 2217 m, Monte Vettore 2476 m) the highest one reaching 2,912 m (Corno Grande, Abruzzo).

On the Adriatic coasts, the power values are, as expected, levelled downwards, caused by a lower fetch and by the morphological trend of the Italian and Balkan coasts, which reduce the spectrum of the direction of origin of the wave to the second quadrant only.

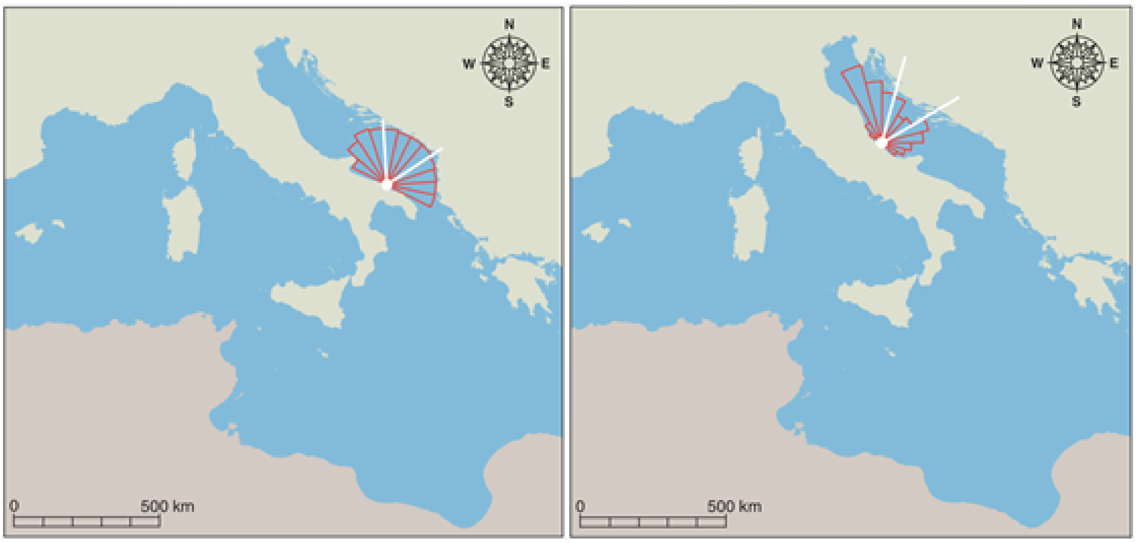
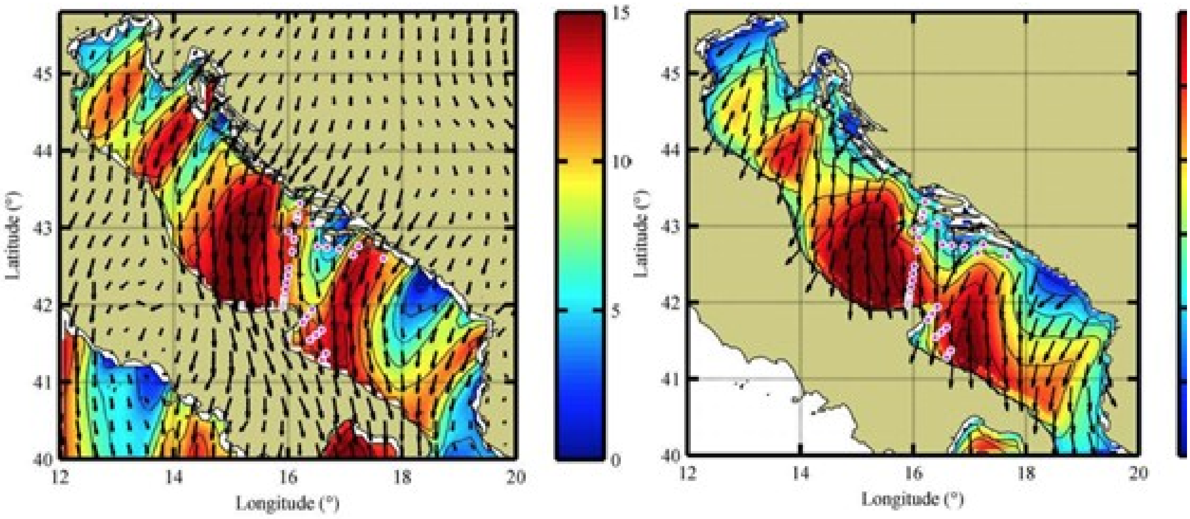


Figure 11 - Fetches in central and south Adriatic Sea (Corsini et al.)

Despite its reduced extension from the point of view of wave energy, the Adriatic Sea can be divided into four specific areas: The North-Eastern Adriatic, the North Adriatic, the Central Adriatic, and the Southern Adriatic. Due to their shape, Bora and Sirocco are dominant winds in the Adriatic and can generate wave motions with significant Hs and Tp.



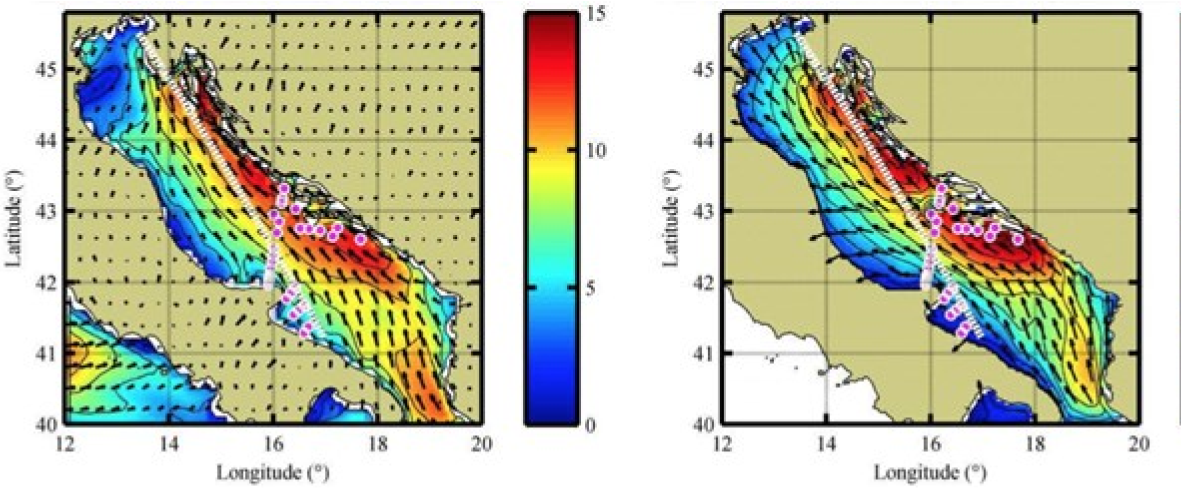


Figure 12 - Difference between Bora and Sirocco storm (Dykes et al. 2009)

Besides direction, these two winds differ in terms of frequency and energy. The waves generated by the Bora come from the north and move towards the Italian coasts. They are less frequent but more energetic. Sirocco waves are parallel to the axis of the Adriatic Sea, but they have a greater incidence on the Croatian coasts and the northern sector of the Italian coast. They are more frequent, but they generate less energy than the waves generated by the Bora, even if the average annual power is about the same.

Wave energy potential in the Adriatic Sea – Italian coast

The potentials of the four sectors were calculated using data from the RON (Rete Ondametrica Nazionale- ISPRA).

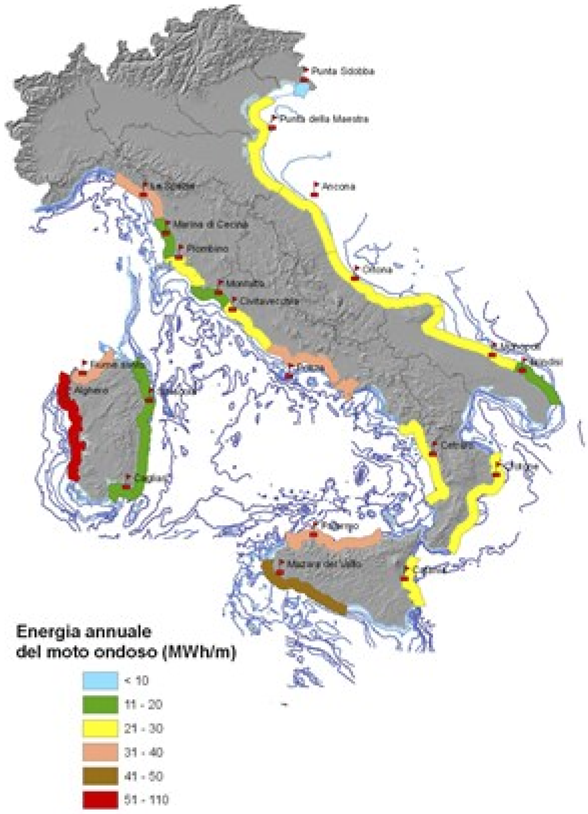


Figure 13 - Italian annual mean wave energy (Peviani et al. 2011)

The north-eastern Adriatic is the one with the most limited potential: the calculations based on the wave buoy data from Punta Sdobba show a potential of 0.17 kW/m.

Moving south, the north Adriatic Sea (from Piave River to Foglia River) has a wave energy potential of 2.75 kW/m; the central Adriatic (from Foglia River to Punta San Francesco) has a 2.6 kW/m potential, and in the southern part of the Adriatic Sea (from Punta San Francesco to Torre Guaceto) the estimated wave energy potential is about 2.57 kW/m.

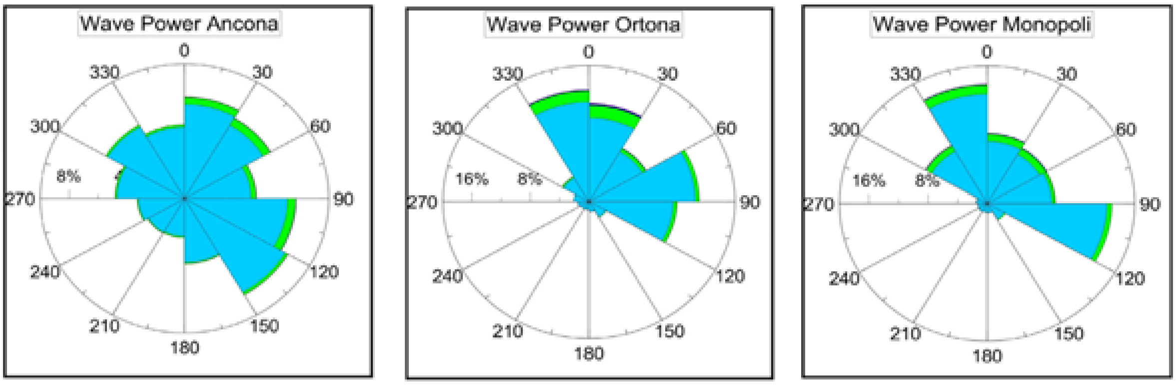


Figure 14 - Wave energy in central and southern Adriatic Sea. (Vicinanza et al.2011)

Finally, the interannual data provided by the WebGIS of the Maestrale project estimate a height of between 0.075 m and 0.961 m a.s.l. The trend of the height varies from NW to SE based on the bathymetry: there are therefore milder waves in the northern Adriatic (Trieste-Venice gulf) and higher waves in the southern part (Gargano-Bari area), with waves of medium height in the central part.

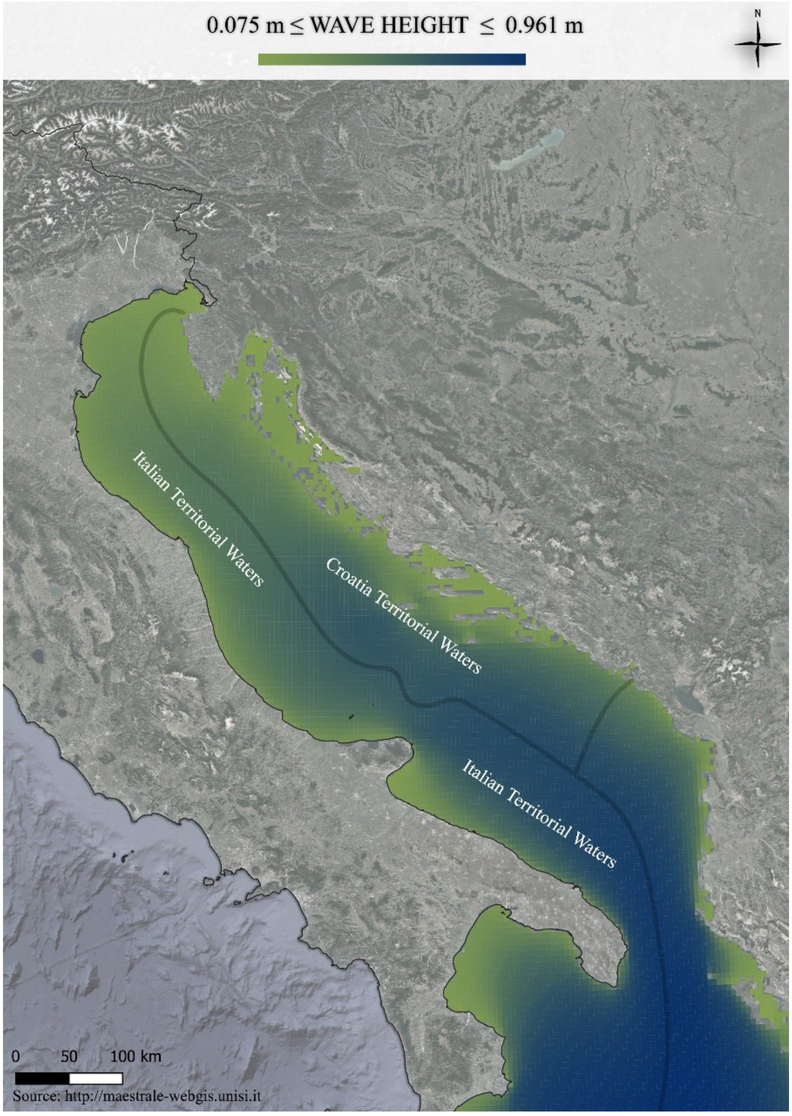


Figure 15 - Wave height

In addition to wave height, data on the interannual averages of wave power have been provided by the Mistral project. Generally, the wave energy potential in the Adriatic Sea is quite limited, with interannual averages between 0.075 kW/m and 1.926 kW/m. The general trend of the power, also, in this case, is in an NW-SE direction with very low potentials for the northern part (0.04-1.31 kW/m in the Gulf of Trieste-Venice) and higher powers in the southern part, especially near Otranto and near the southern Balkan coast.

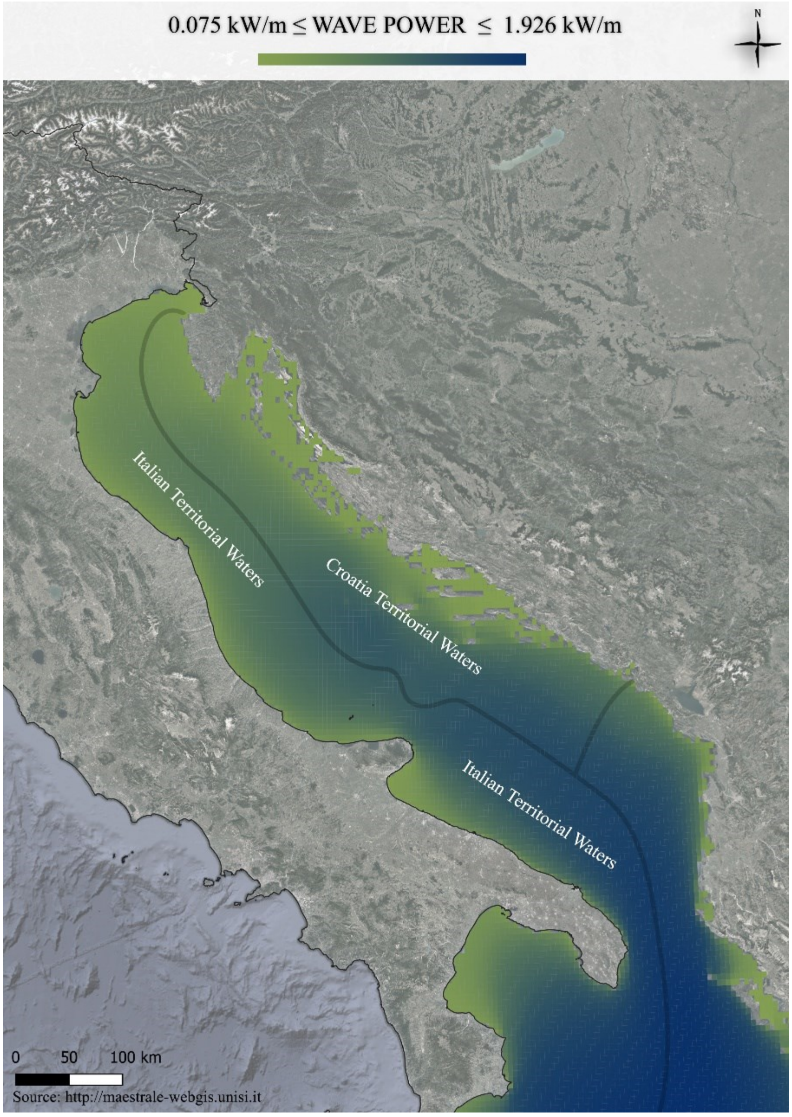


Figure 16 - Wave power

2.2.2 Tidal energy potential

Tidal energy is a resource that can be exploited from the sea level fluctuations due to the tidal range or directly from tidal-driven currents. The estimated global potential for tidal energy is approximately 3 TW, of which 1 TW is technically exploitable. Tidal energy is special in terms that require unique geographic characteristics since the energy potential is dependable on bathymetry, the seabed roughness and mean tidal range. Since the tidal energy potential is in general very low for MED and the Adriatic Sea with seldom information, in the following analysis, only brief data is given obtained from the known potential assessments.

According to Sleiti et al. [8], tidal energy is strongly predictable with very low variations. The overall potential is estimated to be around 3.5 TW. In the case of tidal range, high variation of sea level is expected, while for tidal current-driven turbines following is expected for sufficient production. Turbines should be deployed at least 30 m depth where current velocity is at least 2 m/s. Besides strong predictability, devices for the exploitation of tidal energy have high efficiency of about 80% [9].

2.2.3 Offshore wind energy potential

Offshore wind energy has the most significant potential amongst MRE sources. Mainly, this is because the technology readiness level reached the maturity stage, and even though it is still expensive compared to onshore installations, it is showing great prospects for further utilisation. Nevertheless, since the COASTENERGY project aims to foster the deployment of BE technologies in coastal areas and ports, wind energy was excluded from the in-depth analysis. In the following lines, a brief overview of the offshore wind energy potential is given since it is the most prospective MRE source, and its share is expected to increase even more. This is especially expected with the development of floating platforms, necessary for the MED environment.

Offshore wind turbines are developed on existing experience for onshore counterparts, and due to this fact, they are currently the most mature MRE technology. In comparison to onshore wind, offshore wind exhibit significant advantages since it blows more consistently with lower variability, increasing the load factor and power output. Moreover, since the wind speed increases with the distance from shore, produced power is higher as well. Theoretical offshore wind potential is estimated to be above $2x10^3$ kWh/m^2, while the exploitable capacity is pronouncedly lower. By using Quick Scatterometer observations, it was estimated to be around 39 TW. For the Mediterranean Sea, up to now, there are no commercial projects since the bathymetry, and sea depths requires the usage of floating structure that are still under development. Under the project CoCoNET [10], detailed data from in situ measurements were thoroughly analysed with the following conclusions. Regarding the offshore wind potential at 80m height asl, the highest potential was noted for the Gulf of Lions, followed by the Aegean Sea. For the Adriatic Sea, the potential is significantly lower, as can be seen from Figure 17.

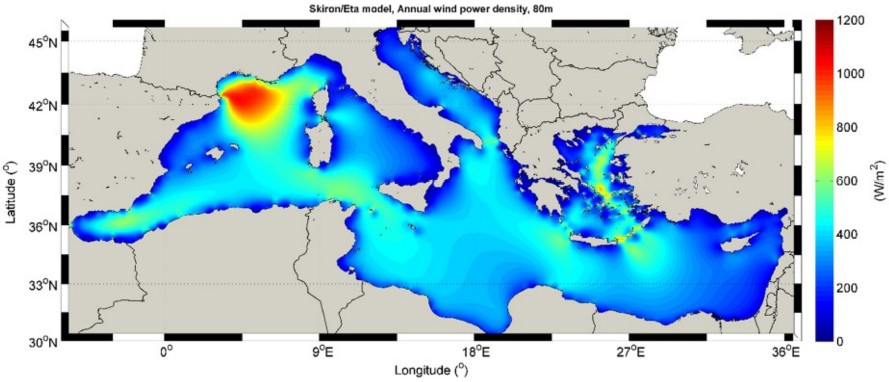


Figure 17 - Mean annual offshore wind power density at 80m height asl according to the SKIRON-Eta model [4]

Furthermore, it is more interesting to observe offshore wind potential regarding the sea bathymetry since the mature technology is now available only for the depths below 30m. From Figure 18, the Adriatic Sea exhibit offshore potential (minimum wind speed >4.1 m/s) for all sea depths, nevertheless, the significant portion of potential is located at higher depths (>40m).

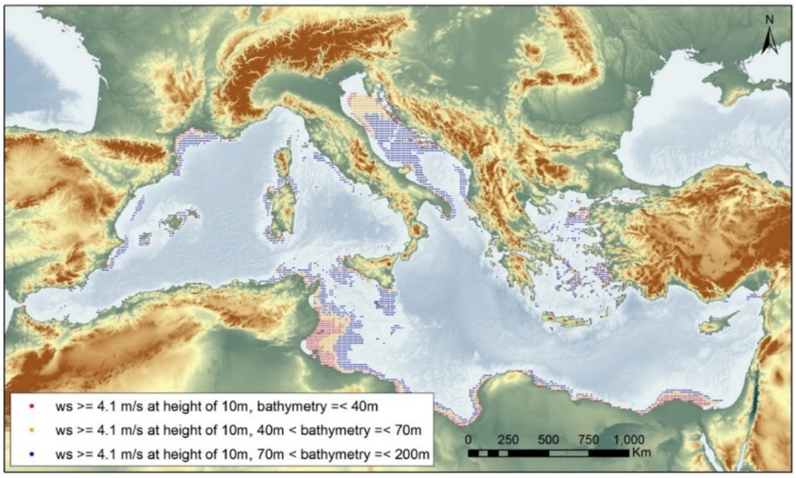
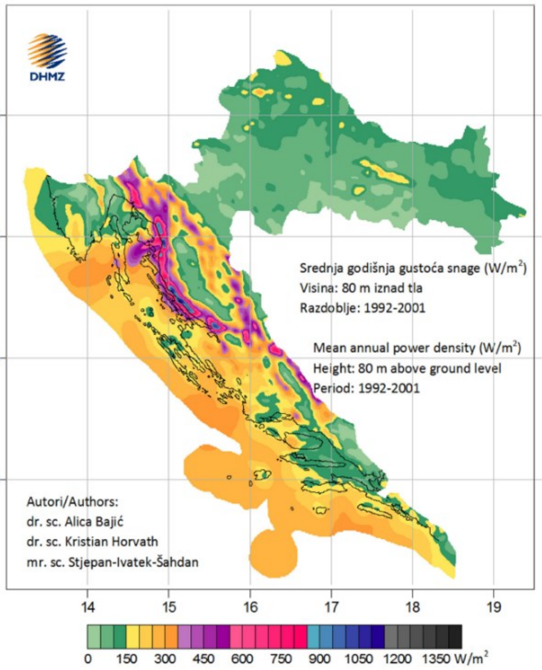
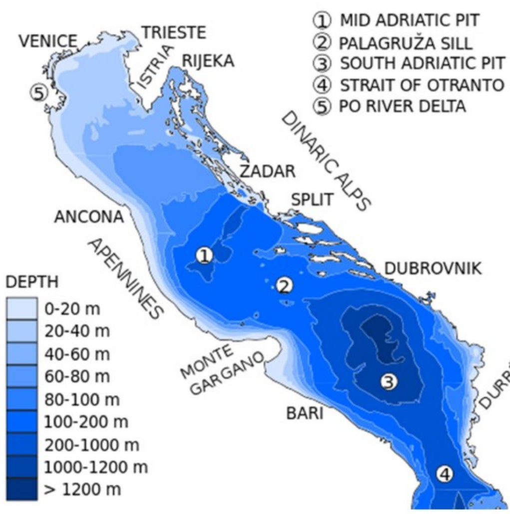


Figure 18 - Offshore wind energy potential with the sea depths [4]

For the Croatian coast, more data is available regarding the offshore wind potential, and it is presented in Figure 19. From Figure 19a) it is visible that the highest annual power density is noticed for the Northern part of the Adriatic, where the Cres-Losinj archipelago is located. Moreover, Figure 19b) presents the detailed Adriatic Sea bathymetry where for Northern part is dominated by shallow waters up to 60 m, which indicates the potential for new installations once when floating structures are developed, and investment costs are reduced.



a) Source: [4]



b) Source: [11]

Figure 19 - Mean annual power density and the Adriatic Sea bathymetry

2.2.4 Thermal energy potential

The hydrodynamics of the Adriatic Sea is characterized by a prevalent anticyclonic circulation. This circulation is more pronounced in winter and spring while in summer and autumn it slows down and a series of anticyclonic and cyclonic revolutions prevail (Artegiani et al., 1997). The anticyclonic circulation is mainly present in winter and is composed of a current coming from the eastern sector of the Otranto Channel, which moves north along the Dalmatian coast and is called East Adriatic Current (EAC), and a current directed south along the Italian coast, which leaves the Adriatic in the western part of the Otranto Channel and is called Western Adriatic Current (WAC).

EAC is characterized by warmer and more saline waters coming from the Mediterranean and Ionian seas. The WEC, on the contrary, carries less saline and colder waters (Artegiani et al., 1997; Poulain, 2001; Civitarese et al., 2010; Korlevic et al. 2015), since it is conditioned by the river water coming from the Alps.

These hydrodynamics also affect the water temperature in the Adriatic Sea. From a thermal point of view, the Adriatic Sea can be divided into three macro areas: northern, central, and southern Adriatic Sea.

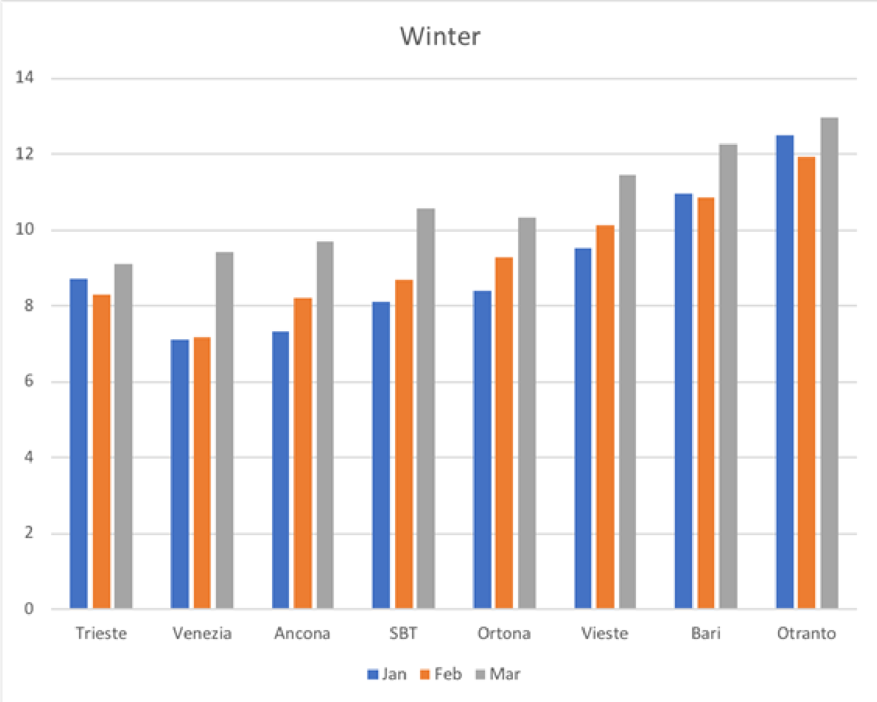
The differences between these three sectors are due to environmental and climatic factors. The seawater temperatures are colder in the northern sectors and become warmer moving towards the southern sectors.

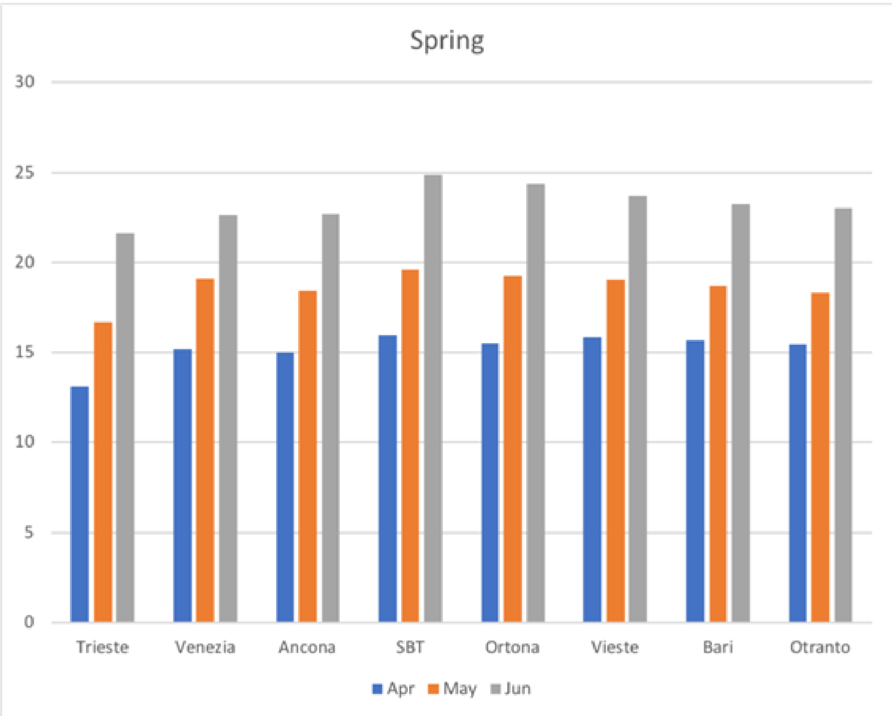
The northern Adriatic (NA) Sea, with an annual average temperature of 16.5°C, is the coldest part, due to the colder climate and to the presence of important river mouths (such as the Po and the Piave) that introduce cold waters into the sea.

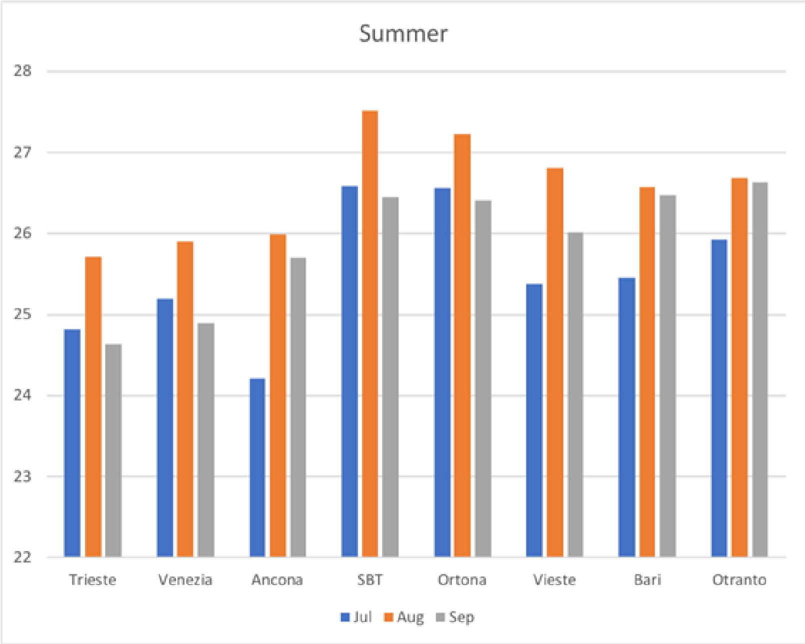
The central Adriatic (CA) sector has an intermediate climate and is characterized by the absence of important rivers, a limited depth, and a geographical position that limits connection with the open Mediterranean Sea, which help in the conservation of the temperatures, which are around 17.6°C.

The southern Adriatic (SA) is the hottest sector with an annual average of 18.5°C despite the higher depths with colder deep waters. This is due to the influence of the masses of water coming from the central Mediterranean and Ionic seas.

During winter and autumn, the difference between average surface water temperature in the three sectors is higher than in spring and summer. The gap between NA and SA during winter and autumn is about 3°C, while it is about 1°C in spring and summer. In the NA, the water temperature varies between 7.8°C in January and 25.8°C in August, with a minimum of 5.7°C and a maximum of 28.7°C. In the CA sector, the surface water temperature varies between 7.94°C in January and 26.7°C in August, with a minimum of 6.2°C and a maximum of 28.7°C. In the SA, the water temperature varies from 10.9°C in January and 26.7°C in August, with a minimum of 7.6°C and a maximum of 29.3°C.


Winter
14
12
10
8
6
4
2
0
Trieste
Venezia
Ancona
SBT
Ortona
Vieste
Bari
Otranto
Jan
Feb
Mar


Spring
30
25
20
15
10
5
0
Trieste
Venezia
Ancona
SBT
Ortona
Vieste
Bari
Otranto
Apr
May
Jun



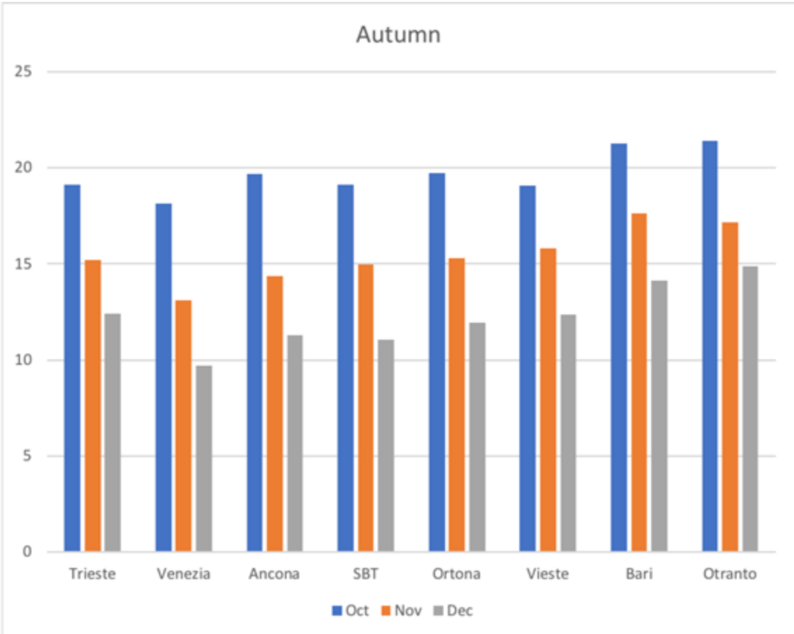


Figure 20 - Surface water temperatures in the Adriatic Sea

By analysing data related to seawater temperatures at a depth of 10 meters, it is possible to observe the difference between the different sectors, and what are the influences of the river waters. In fact, by comparing the areas where river mouths are present with the neighbouring areas, it is possible to observe that the water is colder where there are rivers with constant flows. On the contrary, it is possible to notice how the warmer water coming from the Mediterranean and Ionian seas have effects on the water temperature in the southern sector.

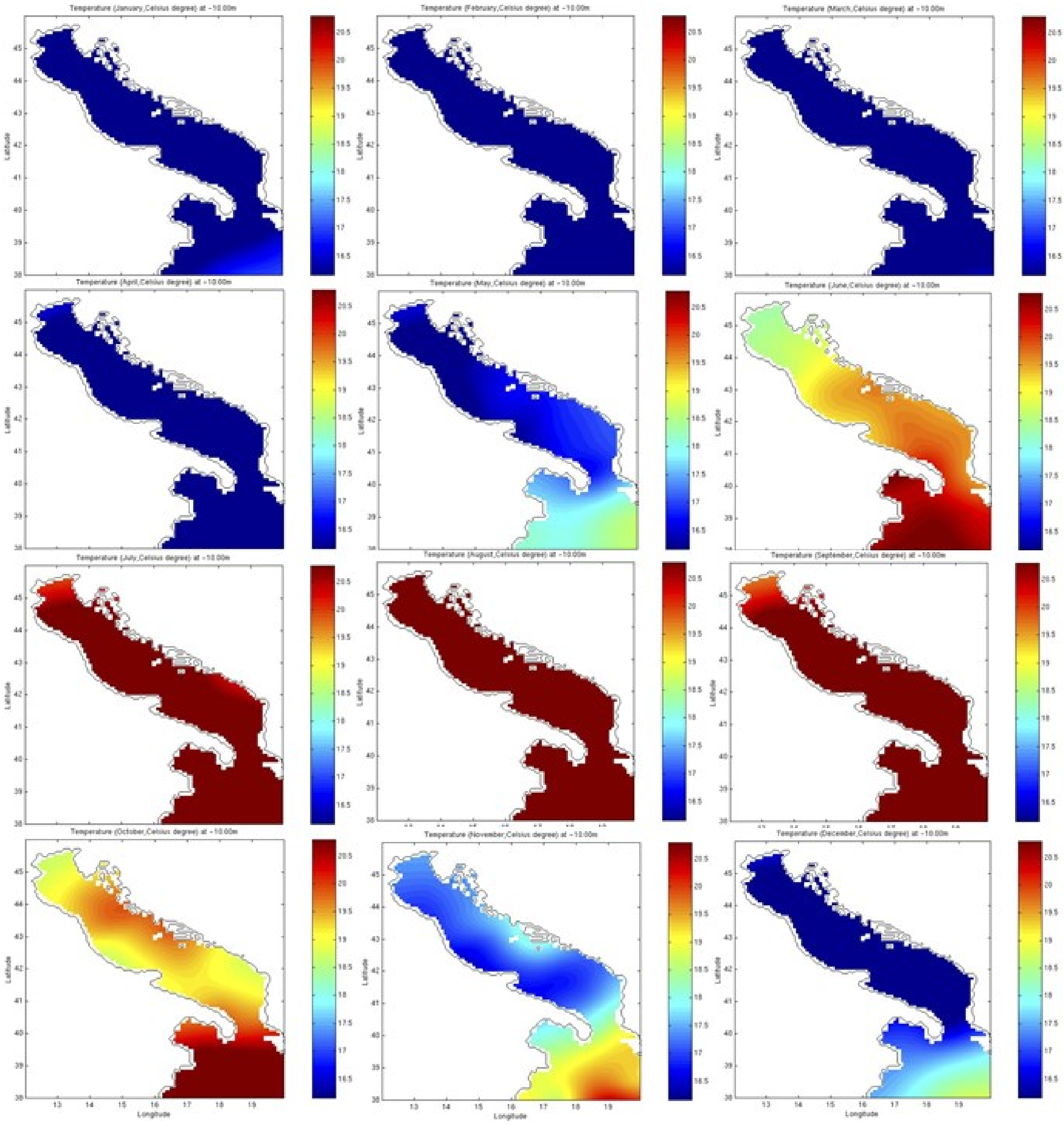


Figure 21 - Monthly temperature variation in the Adriatic Sea at a depth of 10 m

As regards the interannual average potentials of temperature at a depth of 5 meters, it is observed that they oscillate between 16.592 °C and 20.277 °C. Also, in this case, it is possible to divide into three zones according to the potential: high temperatures in the Trieste-Venice basins, medium temperatures in the Gargano area and finally low temperatures between the Apulian coast and the southern Balkan. There are lower temperatures near the Balkan coasts, concerning irregular bathymetry or more pronounced submerged slopes.

On the other hand, if we consider the temperature at a depth of 300 m, the interannual averages oscillate between 13.876 °C and 14.815 °C. Obviously in the second case, at a depth of 300 m, the figure is reduced to restricted areas, considering the bathymetry of the Adriatic basin.

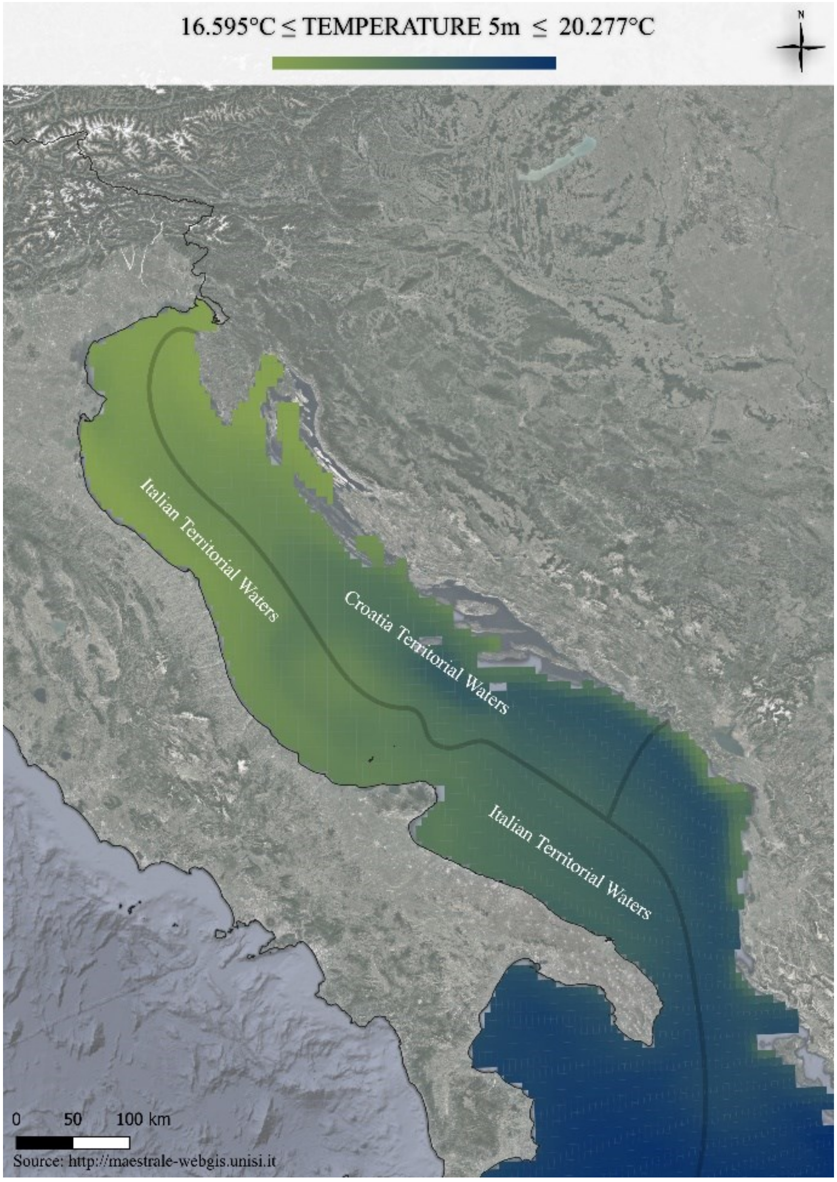


Figure 22 - Temperatures at 5 m depth

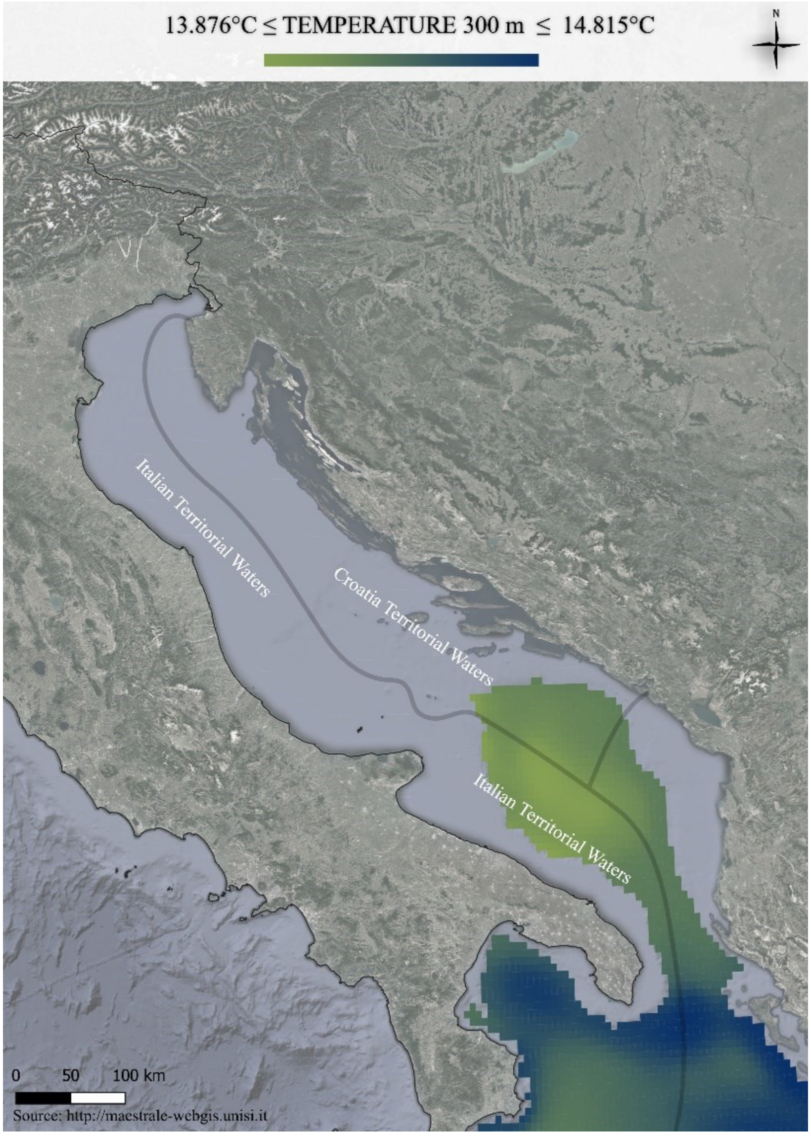


Figure 23 - Temperatures at 300 m depth

There is no general procedure to evaluate the potential for seawater heat pumps. The only thing that is important for their deployment is the presence of seawater and location close to the shoreline to minimise investment costs. The great advantage of seawater lies in the fact that their temperature is more-less constant during the year, as well as the heating capacity of seawater is significantly higher compared to air. The constant temperature of seawater results in a higher coefficient of performance (COP). The average seawater temperature for the Adriatic Sea is between 11 and 24 °C during the year.

2.3 Technology assessment

The marine energy technologies to produce blue energy (BE) can be classified based on their conversion principles in four main categories:

- Wave energy converter (WEC)
- Tidal energy converter (TEC)
- Thermal energy converters
- Chemical energy converters

WECs capture the energy contained in waves and use it to generate electricity. WECs can be categorized into four sub-categories based on their working conversion system: oscillating water columns (OWC); oscillating body converters (OBs) overtopping converters (OTD), and oscillating wave surge converters (OWSC).

TECs use tidal-range technologies such as barrages (i.e., a dam or an isolated turbine) to harvest power between high and low tide.

Thermal energy converters generate power from the seawater thermal gradient. For this technology, the division is based on the scale of the system; big-scale ocean thermal energy converter (OTEC) and small-scale seawater source heat pump. OTEC plants generate power from the temperature difference between warm surface seawater and cold seawater at a depth of 800–1,000 meters, while seawater source heat pumps use the sea like a thermal reservoir and generate power like a normal geothermal heat pump.

The best solution among the **chemical energy converters** is the salinity gradient energy/osmotic power, which exploits the difference in salt concentration, as occurs where a river empties into an ocean. Demonstration projects use “pressure retarded osmosis”, with fresh water flowing through a membrane to increase the pressure in a tank of saltwater; and “reverse electrodialysis”, with ions of salt passing through alternating tanks of salt- and freshwater. Another solution is the algae aquaculture, which makes use of seaweed or its by-products as fuel.

As already mentioned in the previous paragraphs, one of the objectives of COASTENERGY is the evaluation of energy production generated through wave energy and thermal conversion systems. For this reason, only these two systems will be discussed in the following paragraphs

The Blue Energy potential analysis which was carried out in the previous section showed that wave, tidal and offshore wind have limited or very low energy potential. The significant potential is only evident for thermal energy, in case if utilised by seawater heat pumps. For further analysis, the wave energy converters and seawater heat pumps are selected. Even though it was shown that the potential for wave energy in the observed Archipelago is very low, they can be incorporated in existing or future port infrastructure, which is within the scope of the project. Seawater heat pumps are already proven technology with the perspective for even wider deployment. This assessment is carried out by evaluating the technology readiness and applicability for the Adriatic Sea, and by presenting the relevant case study analysis for selected technologies.

2.3.1 Wave energy converters

Wave energy converters still didn't reach the mature stage of the application, and their technology readiness level (TRL) varies between 3-7. There is a wide variety of patents and prototypes developed and tested up to now, with different successes. One of the major drawbacks of bringing technology to a commercial level lies in the fact that there is no universal approach to design. Wave converters can be divided into the shoreline, near-shore, and offshore devices. Additional division can be made on the type of how they are catching the waves; attenuator, point absorber or terminator [14]. Finally, devices are divided by the mode of operation on the Submerged pressure differential, Oscillating wave surge converter, Oscillating water column and Overtopping devices [15]. As can be seen, there is a wide variety of existing prototypes of which some have been tested in an operational environment. Of special interest are those devices that can be incorporated in existing or new coastal infrastructure (i.e., breakwaters). There are two types of such devices:

- Oscillating wave surge converter (OWSC)
- Oscillating water column (OWC)

Oscillating wave surge converter is generally comprised of a hinged deflector, positioned perpendicular to the wave direction (a terminator), that moves back and forth exploiting the horizontal particle velocity of the wave. An example is the Aquamarine Power Oyster, a nearshore device, where the top of the deflector is above the water surface and is hinged from the seabed. A prototype of this device has been constructed [15].

Oscillating water column devices are among the first wave converters developed. They are located on the shoreline or near shore. They are constituted by a submerged structure that contains a chamber with air that is alternatively compressed and uncompressed following the entering waves. The pressure of the air is then converted into energy by a turbine. Some floating devices have been developed on the same principle [15].

In this report, the focus is given to the devices that have been tested as prototypes and can be either incorporated in port infrastructure or installed near-shore. Devices operating on OWC mode are interesting since they can be built-in new breakwaters or seafronts. The ISLAY Limpet was the first commercial power device of such type installed in Scotland in 2000, with a capacity of 500 kW. The Welles turbine was used to generate electricity since such design allows the production when air is passing in both directions. The plant has been decommissioned, and as of 2018 all installations except the concrete construction making up the wave chamber have been removed. Nevertheless, this design inspired the further development of OWC in cases of Mutriku Breakwater Wave Plant, The Resonant Wave Energy Converter (REWEC3) and Overtopping BReakwater for Energy Conversion (OBREC). For the case of analysed location, especially are interesting REWEC3 and OBREC since they are developed in the Mediterranean and the Adriatic Sea, respectively. Figure 24 shows a visualisation of the Islay Limpet installation.

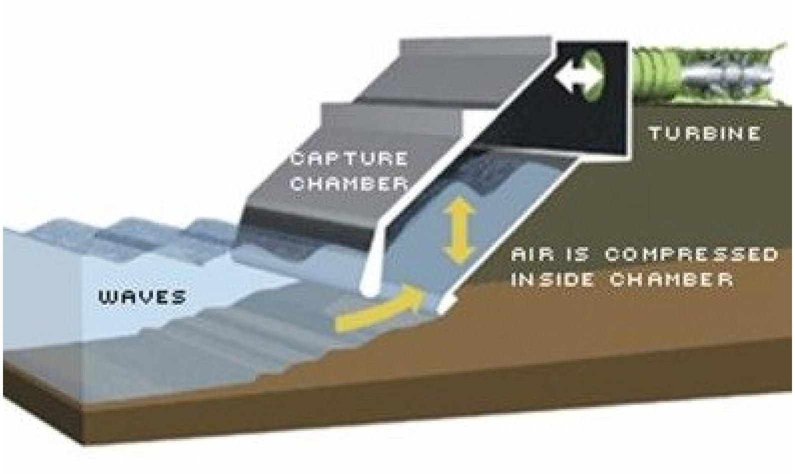


Figure 24 - Visualisation of Isley Limpet device installation [16]

Oscillating water columns

This is the most common WEC typology. These devices are placed parallel to the wavefront and are also called terminators because they can provide a significant obstacle to the propagation of the waves, thus capturing and reflecting the wave energy.

The OWC is based on the action of a column of water oscillating inside a siphon. When the water column enters the siphon, it compresses the air contained therein and increases the internal pressure. The air will come out through a turbine connected to an alternator, which thus converts the wave energy into electricity.

OWC systems are generally installed in an onshore/near-shore position; they have the advantage of being installable in coastal defence structures like dams or harbour structures without generating a high environmental impact.

REWEC3

The Resonant Wave Energy Converter (REWEC3) is a system that was installed in the Port of Civitavecchia’s breakwater as part of the Poseidon project. Like other OWC-based systems, it consists of a chamber with water in the lower part, and air in the upper part and the waves cause air to flow through a turbine connected to a generator. The particularity of this system is the existence of a U-shaped conduit placed before the oscillating water column chamber, aiming to cause a better generation performance. Recent work has demonstrated that resonance with the incident waves occurs without the need for phase control systems, so power generation can be improved if the design of the configuration is appropriate (Arena et al. 2018).

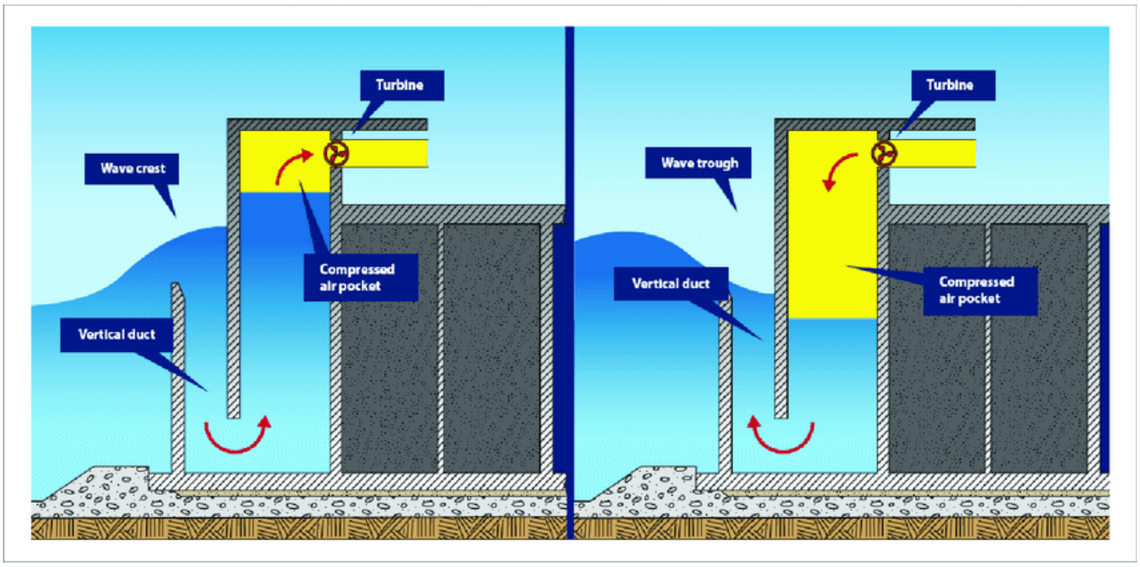


Figure 25 - REWEC3 system (wavenergy.it)

The REWEC3 system is integrated into port structures, however, its installation involves the construction of harbour structures specifically created for this system. In addition to this factor, REWEC3 needs a deep seabed to have a good capacity factor.

PICO

The Pico OWC system consists of a hollow reinforced concrete structure above the water surface that communicates with the sea and the incident waves through a submerged opening on the front wall and communicates with the outside through a fibre duct with an air turbine. Incident waves cause a vertical oscillation of the water column inside the chamber, which in turn causes a flow of air to and from the outside, driving the attached turbine and generator. Important factor in the design of these plants is that the pneumatic chamber must be correctly sized to resonate with the incident sea state.

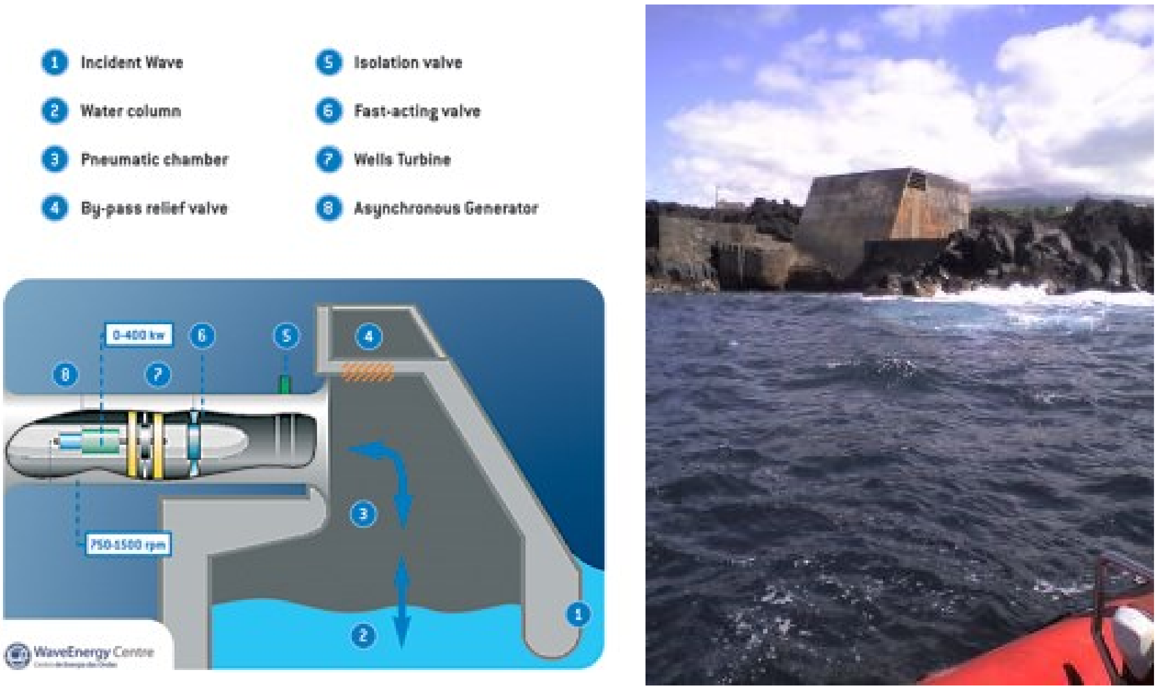


Figure 26 - The Pico system

Pico implies the construction of a new concrete structure, which might have a considerable visual impact. Moreover, as the REWEC3, it needs a deep seabed and a rocky coast.

Oscillating Bodies

The OB systems can be divided into two categories: point absorber and attenuator. The point absorbers are the smaller WECs, generally buoys with a diameter from 3 to 9 meters. They take advantage of the rise/fall of the wave height in a single point and of the possibility of collecting energy from a wave greater than their diameter. They, therefore, do not receive energy from the main wave direction and can capture energy from the waves coming from all directions. This category of devices normally involves a floating structure composed of a first relatively immobile component and a second mobile component moved by the wave motion. The relative motion of the two components is used to drive electromechanical or hydraulic energy converters. Another OB system draws energy from wave power with floats that rise and fall with the up and down motion of waves. The floats are attached by arms to a specific converter station or integrated into a structure like a harbour structure. The motion of the floats is transferred via hydraulics into the rotation of a generator, producing electricity. The attenuator devices are floating structures, which work when oriented parallel to the direction of wave propagation. In some cases, the devices are oriented in a single direction because they are fixed to the seabed, in other cases, they can rotate to be positioned parallel to the wave direction. Generally, they are composed of several segments connected, for an overall length equal to or greater than the wavelength. The different wave heights along the development of the device produce the bending of the parts connected; this movement activates the pumps that are generally housed between each pair of segments. The pumps supply the accumulators, and from there, the pressurized fluid drives the generators.

AquaBUOY

The AquaBuOY is a point absorber consisting of a floating buoy mounted above a piston contained inside a tube, opened on both ends, with a hose pump attached to each end (Dunnet and Wallace 2009). Energy transfer from the motion of ocean waves takes place by converting the vertical component of wave kinetic energy into pressurized water flow through two opposing, full-cycle, hose pumps. Pumped water is directed into a conversion system consisting of a Pelton turbine driving a conventional electrical generator (Weinstein et al. 2004). Bozzi et al. (2018 and 2014) suggest the possibility of downscaling this device to make it more suitable for the conditions of the sea in interest.

a

	Tp (s)									
Hs (m)	6	7	8	9	10	11	12	13	14	17
1	0	8	11	12	11	10	8	7	0	0
1.5	13	17	25	27	26	23	19	15	12	7
2	24	30	44	49	47	41	34	28	23	12
2.5	37	47	69	77	73	64	54	43	36	19
3	54	68	99	111	106	92	77	63	51	27
3.5	0	93	135	152	144	126	105	86	70	38
4	0	122	176	198	188	164	137	112	91	49
4.5	0	0	223	250	239	208	173	142	115	62
5	0	0	250	250	250	250	214	175	142	77
5.5	0	0	250	250	250	250	250	211	172	92

b

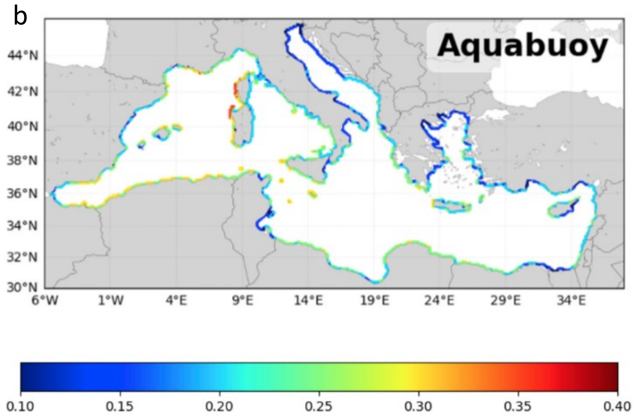


Figure 27 - Aquabuoy power matrix and downscaling factor (Bozzi et al.2018)

Figure 28 - Aquabuoy

A single Aquabuoy has a low potential, which therefore calls for the creation of buoy farms. Also, it needs a seabed of at least 50 meters (Bozzi et al 2014). This system is suitable for a few southern areas only, the Apulian coasts.

Wavestar Energy

The Wavestar Energy draws power from floats that rise and fall with the upward and downward movement of the waves. The floats are connected by arms to a platform that is secured to the seabed. The movement of the floats is transferred through hydraulics to the rotation of a generator, producing electricity. The waves run along the length of the machine, raising 20 floats in turn. Driving the engine and the generator in this way enables continuous production of energy and smooth output. The structure of the system can be easily integrated with the port structure. It is not an onshore system in the strict sense, but it can be considered more like a near-shore system (Marquis et al. 2010).

From a technical point of view, the Wavestar Energy system is suitable for the Adriatic Sea. Its working range is compatible with the central and southern Adriatic Sea sectors, with wave height from 0.5 to 3 m and wave periods from 2 to 13 seconds. The Wavestar can be a good solution in harbour areas, but its visual impact can be a limit for other coastal areas.

Wave height H_{m0} (m)	Wave period $T_{0,2}$ (s)										
	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13
0.0 - 0.5	0	0	0	0	0	0	0	0	0	0	0
0.5 - 1.0	0	49	73	85	86	83	78	72	67	63	59
1.0 - 1.5	54	136	193	205	196	182	167	153	142	132	123
1.5 - 2.0	106	265	347	347	322	294	265	244	224	207	193
2.0 - 2.5	175	429	522	499	457	412	372	337	312	288	267
2.5 - 3.0	262	600	600	600	600	540	484	442	399	367	340
3.0 -	Storm protection										

Figure 29 - Wavestar energy power matrix (Marquis et al. 2010) and float prototype

Wave Clapper

This system draws energy from wave power throughout uniquely shaped floaters, which rise and fall with the up and down motion, lifting force, change of water level, hydraulic air lock, and incident flux of waves. The floaters are attached by robust arms to any type of structure, such as breakwaters, jetties, piers, poles, and floating and fixed platforms. The motion of the floaters is transmitted to an onshore power station, which converts the energy from this motion into fluid pressure, spinning a generator and producing electricity.

Wave Height (m)	Wave period (s)											
	4	5	6	7	8	9	10	11	12	13	14	15
0.51	79.49	63.60	53.00	45.43	39.75	35.33	31.80	28.91	26.50	24.46	22.71	21.20
1	317.98	254.38	211.98	181.70	158.99	141.32	127.19	115.63	105.99	97.84	90.85	84.79
1.5	715.45	572.36	476.96	408.83	357.72	317.98	286.18	260.16	238.48	220.14	204.41	190.79
2	1,000.00	1,000.00	847.94	726.80	635.95	565.29	508.76	462.51	423.97	391.36	363.40	339.17
2.5	1,000.00	1,000.00	1,000.00	1,000.00	993.68	883.27	794.94	722.67	662.45	611.49	567.82	529.96
3	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	953.93	880.55	817.65	763.14
3.5	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00
4	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00

Figure 30 - Power matrix for a Wave Clapper power station with an installed capacity of 1MW and 100 floaters (Eco Wave Power)

The Wave clapper is one of the best WEC systems for the sea state of the Adriatic Sea. It needs waves with limited power to convert into energy, and it can be fixed on existing structures like harbour breakwaters, or other coastal anti-erosion structures such as dams. Like the Wavestar system, it can work with a good capacity factor in the central and southern Adriatic sectors.

Figure 31 - Wave clapper installed on an existing structure (Gibraltar – EWP)

ISWEC

The Inertial Sea Wave Energy Converter (ISWEC) is a wave energy converter composed mainly of a single offshore floating body with a slack mooring. The waves tilt the buoy with a rocking motion that is transmitted to a fully sealed internal gyroscopic system composed of two units. The first main advantage of such a technology is the total absence of any seal, joint or part in relative motion in the harsh sea environment, avoiding problems of corrosion and thus decreasing maintenance expenses while respecting the sea environment; the only components immersed in the marine environment are the mooring and the electrical cable. Electricity generation is based on the conservation of the angular momentum of the internal gyroscope (Bracco et al. 2011). In normal energy production operation mode, the device is aligned with the wavefront direction and the waves make the floater pitch. The floater pitching motion combines with an internal flywheel spinning velocity, thus originating an inertial gyroscopic torque acting on an internal precession axis. An electric motor is mounted on this shaft, and electricity is generated by breaking its motion.

ISWEC is an offshore WEC, a model with a peak power of 50 kW that was installed in the central Adriatic thanks to a partnership between ENI and POLITO. The characteristics of ISWEC are suitable for waves motion typical of the offshore Adriatic.

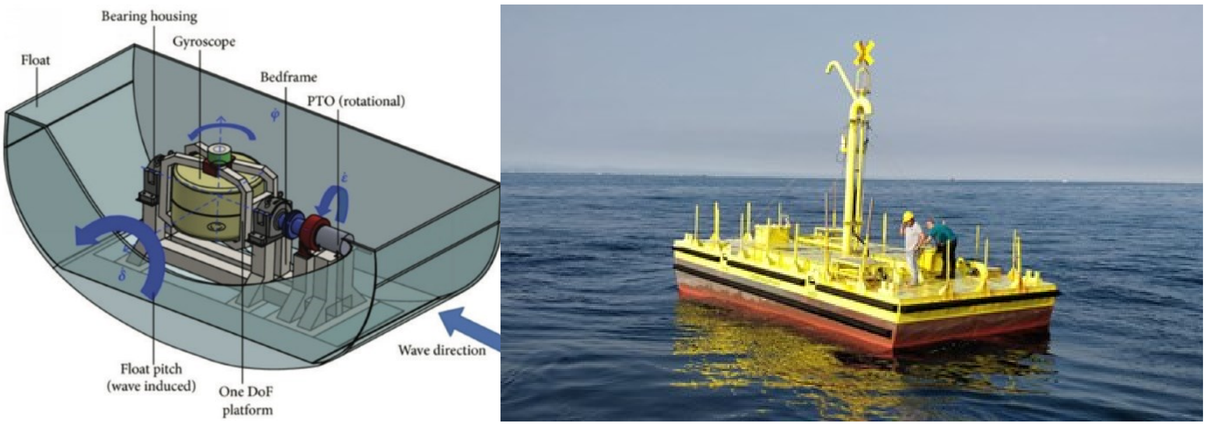


Figure 32 - ISWEC

Pelamis

Pelamis is an attenuator WEC system. It is a semi-submerged articulated structure composed of cylindrical sections linked by hinged joints. The wave-induced motion of these joints is resisted by hydraulic rams, which pump high-pressure oil through hydraulic motors via smoothing accumulators. The hydraulic motors drive electrical generators to produce electricity. A 750-kW device would be about 150 metres long and 3.5 metres in diameter (Carcars 2003). Bozzi et al. (2018 and 2014) suggest a downscaling of the device to make it suitable for the regional sea states and to improve the Pelamis capacity factor.

Hs (m) \ Te (s)	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12
1	0	22	29	34	37	38	38	37	35	32	29	26	23	21	0
1.5	32	50	65	76	83	86	86	83	78	72	65	59	53	47	42
2	57	88	115	136	148	153	152	147	138	127	116	104	93	83	74
2.5	89	138	180	212	231	238	238	230	216	199	181	163	146	130	116
3	129	198	260	305	332	340	332	315	292	266	240	219	210	188	167
3.5	0	270	354	415	438	440	424	404	377	362	326	292	260	230	215
4	0	0	462	502	540	546	530	499	475	429	384	366	339	301	267
4.5	0	0	544	635	642	648	628	590	562	528	473	432	382	356	338
5	0	0	0	739	726	731	707	687	670	607	557	521	472	417	369
5.5	0	0	0	750	750	750	750	750	737	667	658	586	530	496	446
6	0	0	0	0	750	750	750	750	750	750	711	633	619	558	512
6.5	0	0	0	0	750	750	750	750	750	750	750	743	658	621	579
7	0	0	0	0	0	750	750	750	750	750	750	750	750	676	613
7.5	0	0	0	0	0	0	750	750	750	750	750	750	750	750	686
8	0	0	0	0	0	0	0	750	750	750	750	750	750	750	750

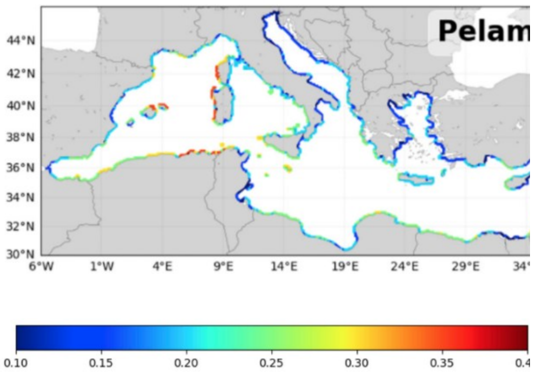


Figure 33 - Pelamis power matrix and downscaling factor related to sea states (Bozzi et al. 2018)

Figure 34 - Pelamis (Garcia et al. 2016)

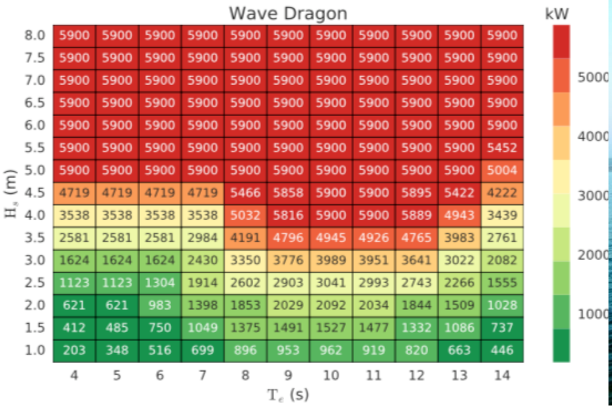
At its normal dimension, the Pelamis working depth is 50 meters. This depth in the northern and central sectors of the Adriatic Sea is very far from the coast, but with a downscaling, this depth would be reduced to 10/15 metres. With this reduction, PELAMIS can be installed in the near-shore area and it would improve its capacity factor. This would contribute to its possible use also in sectors with a lower depth, such as the central and northern Adriatic Sea.

Overtopping converters

The OTDs have a reservoir that is filled with water from waves running up a slope located at a higher level than the surrounding sea. The energy of water flowing back to the sea is used to power a hydraulic turbine to produce electricity. The system operates under a wide spectrum of wave conditions, and high overall efficiency can be achieved. It can be installed along the coast, or on breakwaters, with the consequent advantages for maintenance, control, and use of the generated energy. In some cases, the OTD can be floating and installed in a nearshore/offshore position. Near-shore and offshore WECs can operate with higher wave power because the wave motion has no transformations and power reduction caused by interaction with the sea bottom.

Wave Dragon

Wave Dragon is a floating, slack-moored device based on the principle of overtopping. The machine consists of two symmetrical reflecting wings that focus the waves on a ramp. Behind, the overtopping water is collected and driven to a series of Kaplan turbines, thus converting the difference of potential energy into electricity like in a hydropower plant (Guillon and Chapalain 2018). A 57 m-wide, 237 t prototype of the Wave Dragon, scale 1/4.5 of a North Sea production plant, has been deployed in Nissum Bredning, Denmark, was connected to the grid in May 2003 and tested for several years (Falcão 2010). On a Wave Dragon built for a 36 kW/m wave climate, a wave reflector would be 145 m long and 19 m high. Bozzi et al. 2014, like for Pelamis and Aquabuoy, suggest a downscaling of the device to reduce its dimension to make it suitable for the regional sea states and improve its capacity factor.



H_s (m) \ T_e (s)	4	5	6	7	8	9	10	11	12	13	14
8.0	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900
7.5	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900
7.0	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900
6.5	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900
6.0	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900
5.5	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5452
5.0	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5004
4.5	4719	4719	4719	4719	5466	5858	5900	5900	5895	5422	4222
4.0	3538	3538	3538	3538	5032	5816	5900	5900	5889	4943	3439
3.5	2581	2581	2581	2984	4191	4796	4945	4926	4765	3983	2761
3.0	1624	1624	1624	2430	3350	3776	3989	3951	3641	3022	2082
2.5	1123	1123	1304	1914	2602	2903	3041	2993	2743	2266	1555
2.0	621	621	983	1398	1853	2029	2092	2034	1844	1509	1028
1.5	412	485	750	1049	1375	1491	1527	1477	1332	1086	737
1.0	203	348	516	699	896	953	962	919	820	663	446

Figure 35 - Wave dragon power matrix and view of the prototype

Like other WECs, the full-scale Wave Dragon working depth (around 25 meters) makes it suitable for the Adriatic Sea.

OBREC

The Overtopping Breakwater for wave Energy Conversion is integrated with a traditional breakwater and can be considered an innovative, non-conventional breakwater. In the machine room, a set of low head turbines convert potential energy, from water stored in the reservoirs, into kinetic energy and then into electric energy using generators. For upcoming commercial applications, the traditional Archimedean screw turbine could be safely used, which is one of the oldest and most efficient very low head turbines (Contestabile et al. 2017). This screw turbine works on a very low head, starting from 1 m or less, and requires relatively low flow rates for generating electricity at a significant level. OBREC is the first overtopping WEC integrated into an existing breakwater (Cascajo et al. 2019).

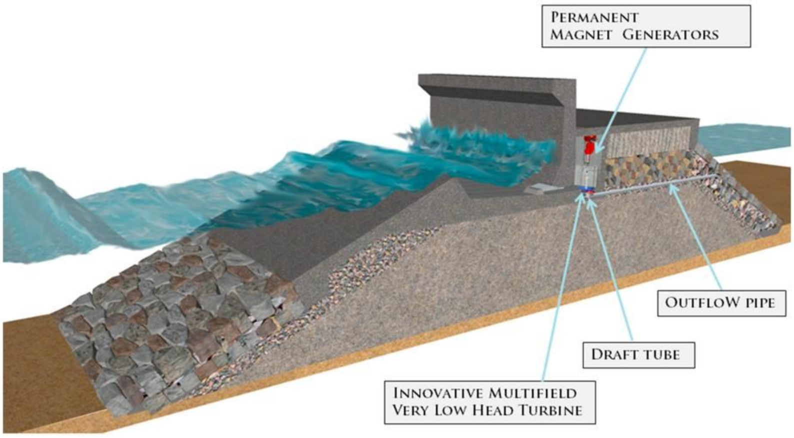


Figure 36 - Scheme of OBREC system

OBREC, like the REWEC3 system, is integrated into port structures or adherent dams for preventing coastal erosion. In comparison with REWEC, the OBREC installation can be possible by modifying some sectors of the structures. Its working sea state is suitable for the Adriatic Sea wave motion, for this reason, it can be installed in the different ports and adherent barriers existing mainly in the central and southern Adriatic.

Oscillating wave surge converters

These devices are simple pitching flaps, oscillating around a fixed axis close to the sea bottom, they are therefore suitable for shallow and intermediate water depths. They have a hydroelectric machinery system, where a pump placed at the rotating shaft pumps pressurized hydraulic oil to a shoreline station, where the hydraulic energy is used to drive an electric generator. OWSC systems have the advantage of being useful for limiting the erosive action of the wave motion on the coasts.

WaveRoller

WaveRoller is an oscillating wave surge converter that converts ocean waves to electricity through a flap that moves and absorbs the energy. The back-and-forth movement of the flap is converted to the rotation of a generator thanks to a hydraulic system. The electricity output of the generator is then transferred to the shore by a subsea cable. WaveRoller operates in near-shore regions at depths of between 8 and 20 m, approximately 0.3-2 km from the shore. It is anchored to the seabed and depending on tidal conditions it is mostly or fully submerged (Mäki et al. 2014).

Hs (m)	Te (s) 5	6	7	8	9	10	11	12	13	14
1	0.043	0.051	0.060	0.062	0.065	0.065	0.064	0.061	0.061	0.057
2		0.198	0.226	0.238	0.232	0.240	0.233	0.225	0.212	0.197
3			0.465	0.485	0.491	0.454	0.463	0.454	0.440	0.408
4				0.744	0.697	0.782	0.745	0.698	0.722	0.659
5					0.973	1.000	0.998	0.982	0.953	0.889

Figure 37 - Waveroller power matrix and rendering of an installation

The WaveRoller device works in a near-shore position, at depths from 8 to 25 m. For its shape and working principle, it can function both as a WEC and as an anti-erosion barrier without impacting the landscape because it is a submerged barrier. Its working depth is such that the system is suitable in the Adriatic Sea.

Oyster

Oyster is essentially a wave-powered hydroelectric plant located at a nominal water depth of 12 m, which in many locations is relatively close to the shoreline. The system comprises a buoyant flap, 18 m wide and 10 m high, hinged at its base to a sub-frame, which is pinned to the seabed using tensioned anchors. The surge component in the waves forces the flap to oscillate. This oscillation compresses and extends two hydraulic cylinders mounted between the flap and the sub-frame, which pump water at high pressure through a pipeline back to the beach, where there is a modified hydro-electric plant consisting of a Pelton wheel turbine driving a variable speed electrical generator coupled to a flywheel. Power flow is regulated using a combination of hydraulic accumulators, an adjustable spear valve, a flywheel in the mechanical power train and rectification and inversion of the electrical output (Whittaker et al. 2007).

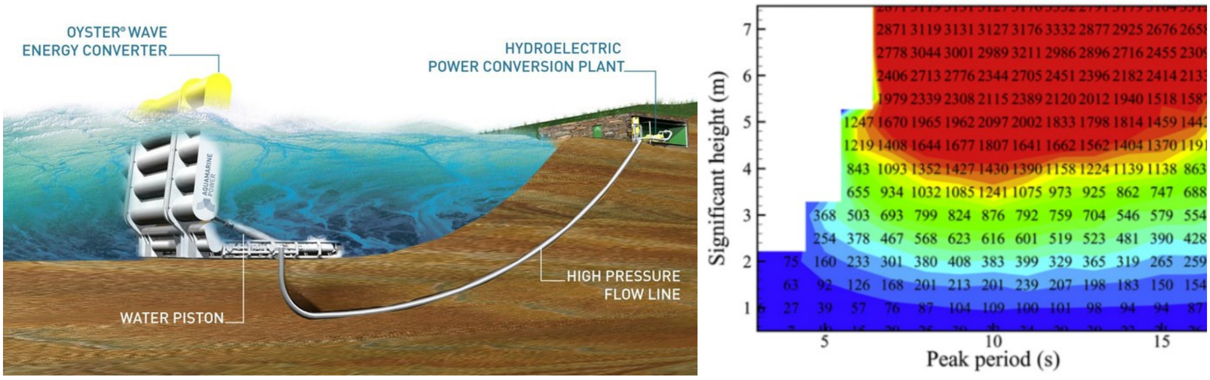


Figure 38 - Scheme and power matrix of the Oyster system (Babarit et. al 2012)

The features of Oyster are like those of the WaveRoller device: working in the near-shore zone, it absorbs the energy contained primarily in the horizontal motion of water, reducing the wave power at the shoreline. A little emerged part of the Oyster flap is the only difference between Oyster and Waveroller. Oyster applies to the Adriatic Sea and, like the WaveRoller, it can help protect the coast from wave erosion.

Additional examples

Mutriku Wave Power plant (Basque County) generates over 1 GWh of clean electricity each year. The plant has an installed capacity of 296 kW, and it is integrated with an existing breakwater at Mutriku harbour, the Bay of Biscay in the length of 100 m of the outer breakwater wall. Foundations are 0.50 m in-depth, and the installation takes 14.25 m in width. The installed device is operating on the principle of OWC same as those of the REWEC3 plant, and it is developed following the Limpet example. Again, since the new breakwater was planned anyway, the addition of WEC didn't have any negative environmental or social impact.

Figure 39 - Breakwater with installed wave energy converter in Mutriku [19]

Triton II is an onshore wave energy converter. The main features of the Triton II device are the following: simple design with low construction and O&M costs, long service life, the foundation is based on land, and it can be used in combination with a breakwater, pier or harbour, utilization of the wave reflection on the wall of the pier, innovating power transmission system, high conversion efficiency and high output power quality. The converter is composed of two main parts; the float, moving up/down following the vertical movements of the sea surface and the mechanism, which converts the vertical movements to horizontal and/or to rotational depending on the type of electrical generator used. A shoreline of 100 m length and 5 m width is enough for a group of 40 converters with floats of 2 m diameter and raising forces more than 3600 kg each. Consequently, although the float is moving in two directions (upwards and downwards), the shaft of the generator rotates always in one direction. All units except floats are housed and firmly protected.

The Jaffa Port (Israel) site is a test for Eco Wave Power (EWP) converters. The site has a single unit of 10 kW capacity, and nominal annual production is 96.36 MWh. The converters extract wave energy from sea-level changes in surface waves. Floater’s motion is transmitted to a local power station where is a pressurized fluid that is used to spin a generator and produce electricity. The main advantage of such a device is simplicity and the fact that it does not require any foundations or special structure for installation. They can be easily attached to existing breakwaters, jetties, piles, floating and fixed platforms. Figure 40 shows the installation of a prototype in the port of Jaffa.

Figure 40 - Installation of EWP converters at Jaffa port [20]

In 2016, the EWP prototype was installed near Gibraltar. The initial power plant was 100 kW and should be expanded to reach 5 MW in the next years. The wave energy converters use floaters attached to a fixed structure. The floaters move up and down with the movements of the waves; the motion is then transmitted to a power station located on land that converts the energy into pressure, used to spin a generator producing electricity. The floaters and pistons are in the water, whereas all the technical equipment operates on land, thereby improving reliability and providing easy access for maintenance and repair.

2.3.2 Thermal energy converters

Thermal energy conversion systems are used to utilize the thermal energy of the oceans and seas. The first technology is ocean thermal energy converters, which are run by the temperature difference between the waters at different depths. This kind of technology can utilize ocean thermal energy for air conditioning, but also electricity generation. Other types of thermal energy conversion system are seawater heat pumps. They are used for heating and cooling and operate on the same principle as other types of heat pumps but use seawater as the heat source which makes them more efficient.

Ocean thermal energy converters

OTECs are hydro-energy conversion systems, which use the temperature difference existing between deep and shallow waters in tropical seas to run a heat engine. Ocean thermal energy converters work on the Rankine cycle, using a low-pressure turbine to generate electric power. There are two general types of OTEC design: closed-cycle plants using the evaporation of a working fluid – such as ammonia or propylene – to drive the turbine-generator, and open-cycle plants using steam from evaporated seawater to run the turbine. Another commonly known design (hybrid plant) is a combination of the two. These plants can cool down the sea by the same amount as the energy extracted from it. Apart from power generation, an OTEC plant can also be used to pump up the cold deep seawater for air conditioning and refrigeration, if it is brought back to shore. Also, the enclosed seawater surrounding the plant can be used for aquaculture.

Seawater heat pumps

The operation of an SWHP is the same as a traditional heat pump, which, by exploiting the Carnot cycle, can produce the necessary energy from a small temperature delta to bring the fluids that circulate through the system at potential temperatures. Compared to a traditional geothermal scheme in coastal areas, the installation of heat pumps can have further advantages because if the water is taken from offshore/near-shore areas, coring will not be necessary for the installation of the pipes. On the other hand, if the SWHP installation is in the coastal area, the depth to reach water at constant temperature is not so high, with a saving on construction costs.

In summer, the heat pump is used as a chiller and seawater is used as a heat sink. The offshore seawater is drawn in from the intake structure and pipeline by onshore pumps. It is filtered and pumped through the condensers of parallel heat pumps, where heat is transferred from the coolant fluid to the offshore water system. Chilled water is generated in the evaporators and supplied to buildings. In winter, seawater is used as a heat source. The heat is transferred from the offshore seawater to the refrigeration fluid in the evaporators. Hot water for heating is produced in the condensers and conveyed via a pipeline to the buildings.

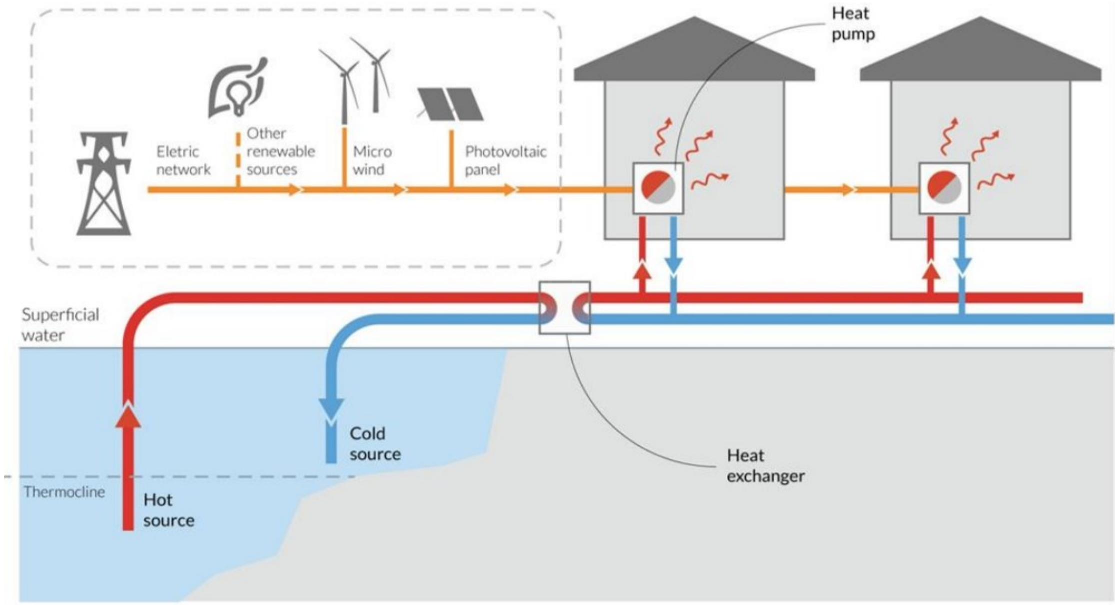


Figure 41 - Scheme of an open-loop ring for seawater sampling and secondary closed-loop ring (Valcovich et al. 2014)

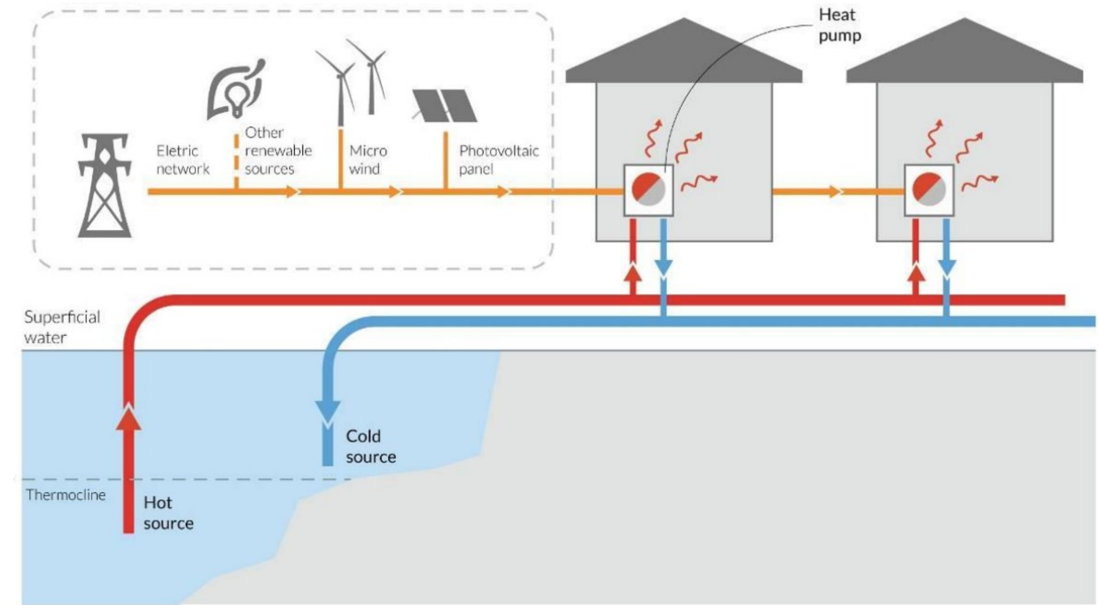


Figure 42 - Scheme of the direct open-loop ring for seawater sampling serving heat pump systems to final users (Valcovich et al. 2014)

The first system, based on an open-loop ring with a secondary circuit, is characterized by two separate rings and consists of the following phases:

- withdrawal of seawater (hot sink);

- passage of water through the main heat exchanger, in which part of the thermal energy is transferred to a technical fluid circulating in a closed loop;
- reintroduction of seawater in the gulf at a point far enough from hot sink to avoid a "hydrothermal short circuit", e.g., mixing of the flows pumped from and re-entered to sea, and therefore a mutual influence between those two thermals states.
- fluid feed to various final users, each equipped with a heat pump system, which will transfer the thermal energy to a second heat transfer fluid used for air conditioning and hot water production.

The second system differs from the first one since the secondary ring is missing: the water coming from sea withdrawal is fed directly to final users so that the heat exchange only occurs at the heat pumps systems. (Valcovich et al. 2014).

Any heat pump installation can provide heating and cool in parallel [22]. The working principle is identical to ground source units: instead of a closed-loop heat exchanger with a transfer fluid, they use water directly (open loop). Water source heat pumps can be connected to aquifers, rivers, lakes or the sea, and wastewater, cooling water from industrial systems, or a district heating system. Seawater heat pumps use water as an energy source and a hydronic system for energy distribution production (floor/wall heating or radiators) [23]. Basic principles for heat pumps seawater intake are given in Figure 43.

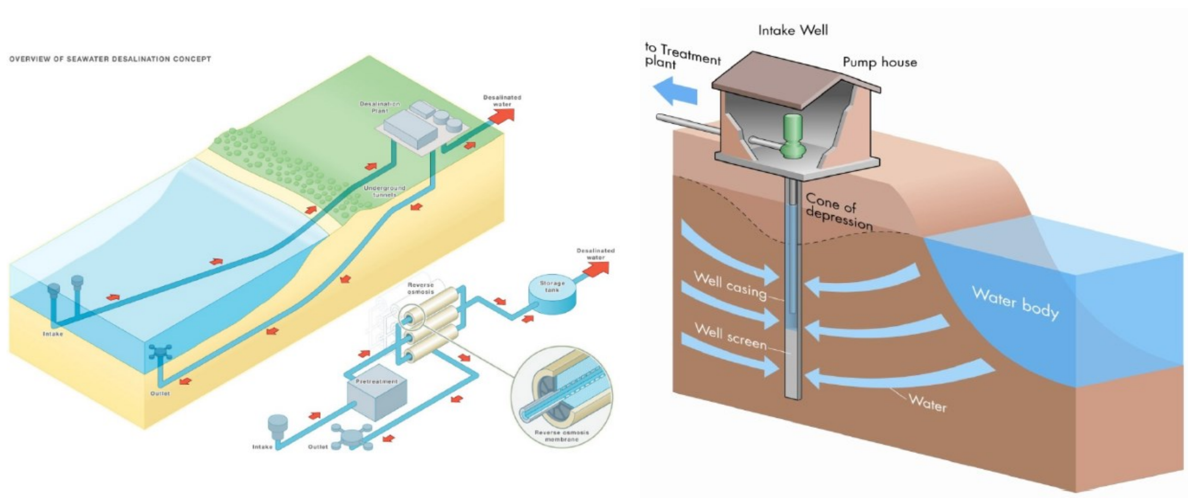


Figure 43 - Basic seawater heat pump system with direct water intake (left) and with the dwelling (right) [24]

For **private households,** a solution with a seawater heat pump can be applied to take advantage of using sea thermal energy from the nearby sea, to improve the performance of the domestic hot water (DHW) and heating, ventilation, and air conditioning (HVAC) systems. Excellent qualities of low energy building also added to the effect of the project. The system was put in use in July 2007. The complete domestic hot water, heating and cooling demand were met with an installed heat pump system without a need for additional heating and cooling system. The applied heat pump system (geoTHERM VWS 101/2) is used for the total heated surface of 260 m^2, utilizes yearly average seawater temperature of 13°C, has a coefficient of performance (COP) for heating of 5.5, and Energy efficiency ratio (EER) for passive cooling of 25-30.

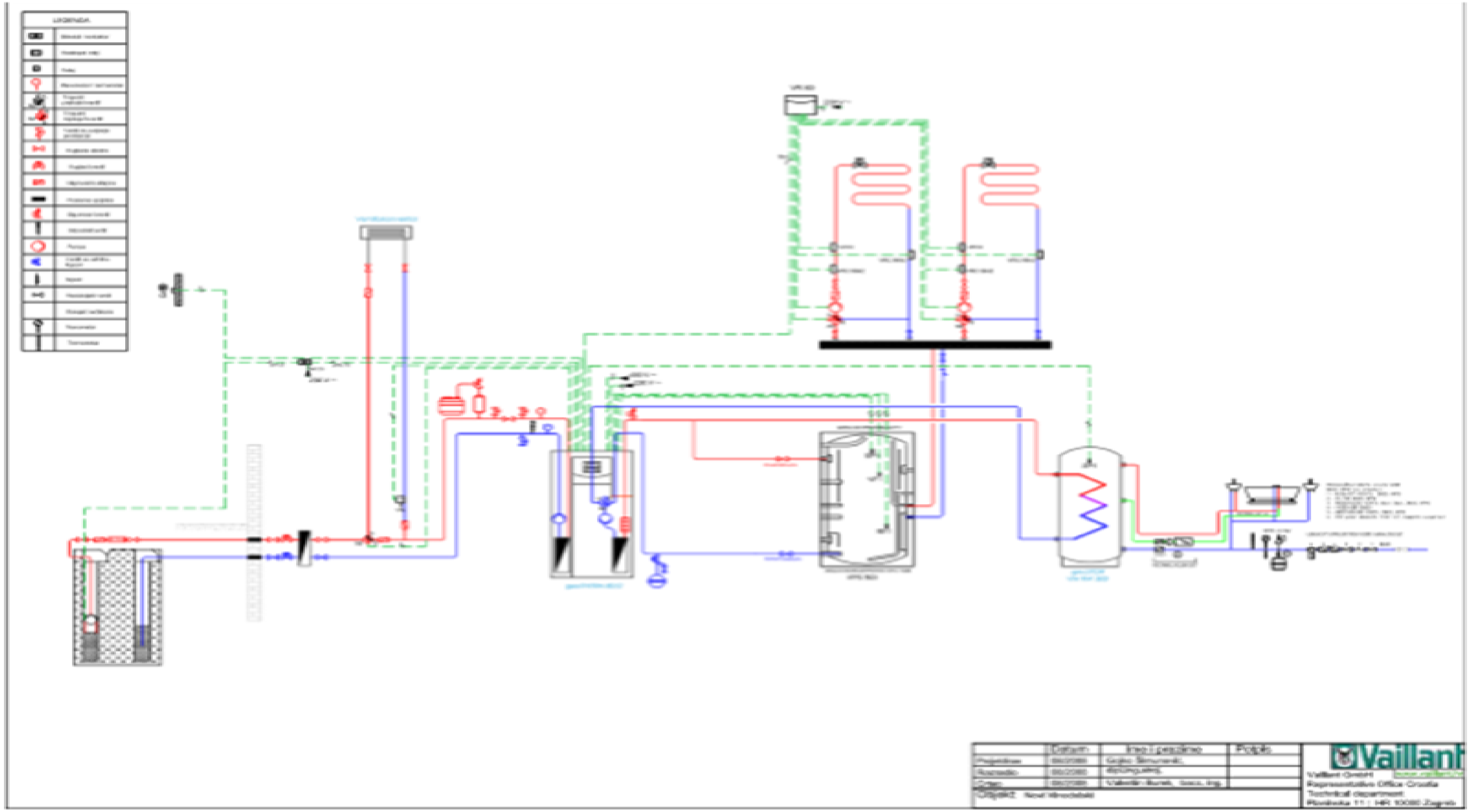


Figure 44 - Schematic depiction of the applied heat pump system for the private household

Figure 44 gives an insight in schematic depiction of the applied system, while Figure 45 shows the installed system (left) and heat pump (right).

Figure 45 - Heat pump system for the private household

A similar system with multiple heat pumps can be used for the **apartment building** (Figure 46) as well. Excellent qualities of low energy building also added to the effect of the project. The system was put in use in September 2008. The complete domestic hot water, heating and cooling demand are met with an installed heat pump system without a need for additional heating and cooling system. The applied heat pump system (Geothermal-geoTHERM VWS 171/2) is used for the total heated surface of 520 m^2, utilizes a yearly average seawater temperature of 13°C, has a COP for heating of 5.5, and COP for passive cooling of 25-30.

Figure 46 - The apartment building, Pazdigradska ulica, Split

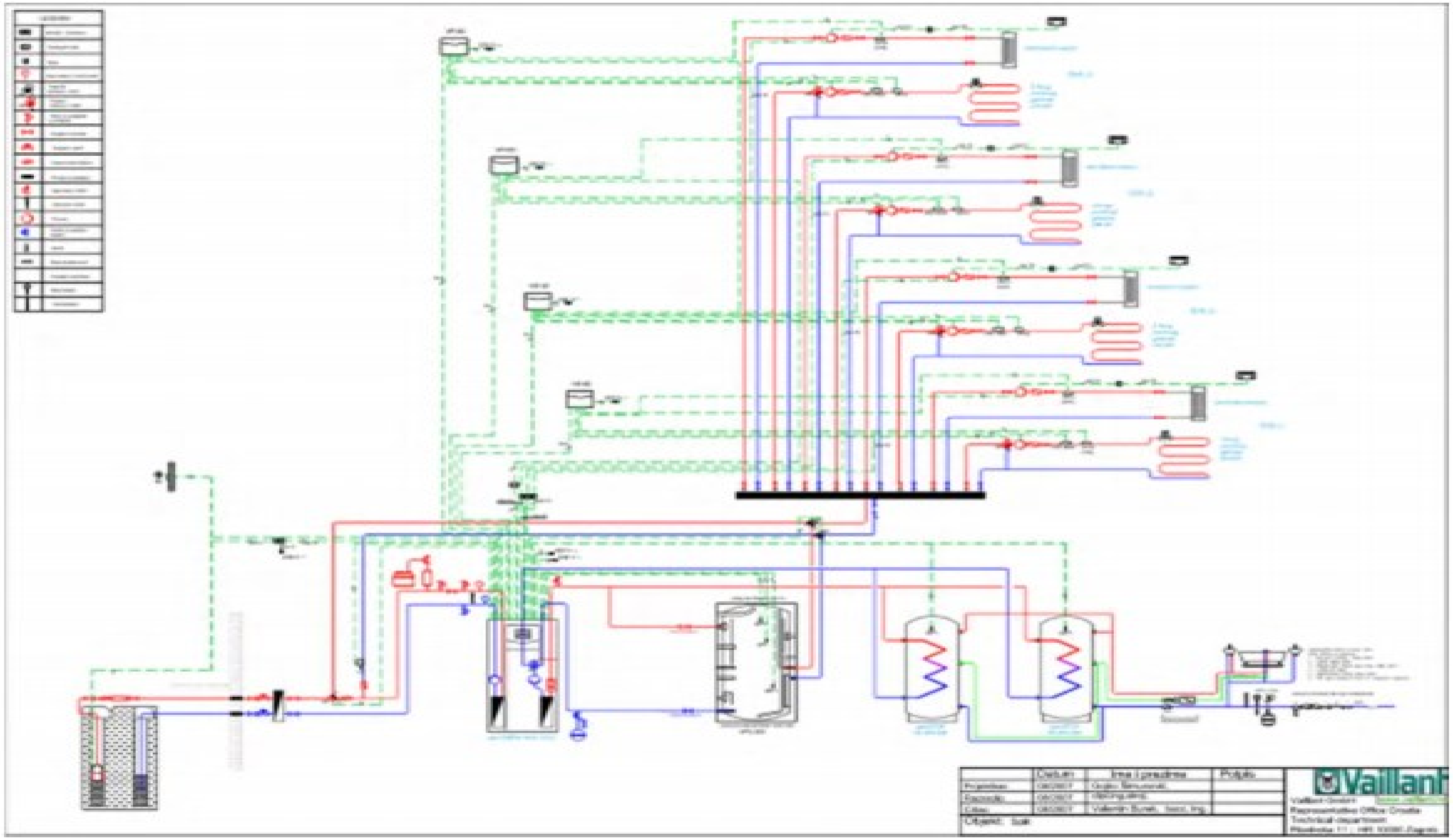


Figure 47 - Schematic depiction of the applied heat pump system for the apartment building

A bigger system is deployed in **Hotel La Meridien Lav,** Podstrana (Figure 48). The applied heat pump system of the 3x1.14 MW thermal capacity utilizes a yearly average seawater temperature of 11 °C, has a COP for heating of 4. Figure 49 and 50 shows a schematic depiction and engine room of the installed system, respectively.

Figure 48 - Hotel La Meridien Lav, Podstrana

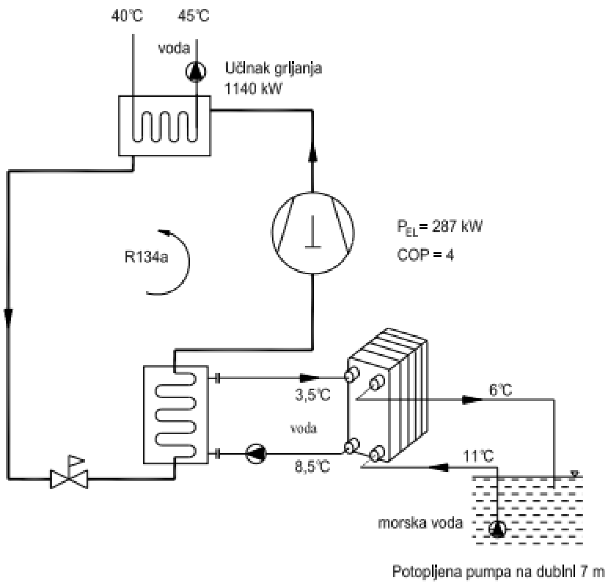


Figure 49 - Schematic depiction of the applied heat pump system for the Hotel La Meridien Lav, Podstrana

Figure 50 - Heat pump system for the Hotel La Meridien Lav, Podstrana

A similar system is also used in **Hotel Punta Skala** in Zadar, where the applied heat pump system has a thermal capacity of 3x1.2 MW. Figure 51 shows an engine room in the Hotel.

Figure 51 - Heat pump system for the Hotel Punta Skala, Zadar

The project of the reconstruction of the **Hotel Jadran, Tucepi** will install a system with seawater heat pumps with direct water intake in an open looped system. As for now, only the environmental impact study of the project has been done. The illustration of the seawater intake and outlet system is given in Figures 52 and 53. Moreover, Figure 54 presents the planned activities regarding the maritime domain to deploy a system for water intake.

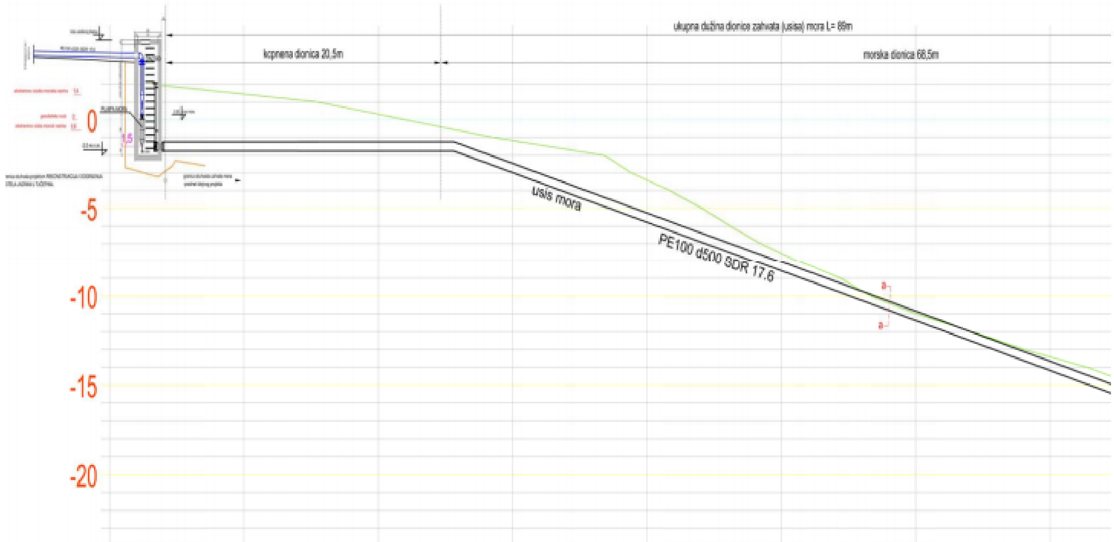


Figure 52 - Intake system for the heat pump system project of the Hotel Jadran, Tučepi

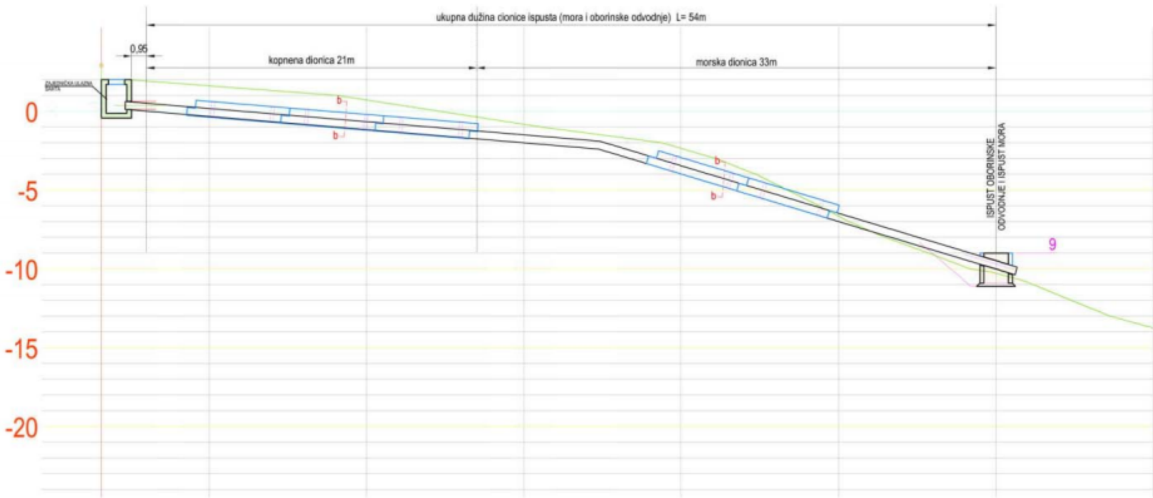


Figure 53 - Outlet system for the heat pump system project of the Hotel Jadran, Tučepi

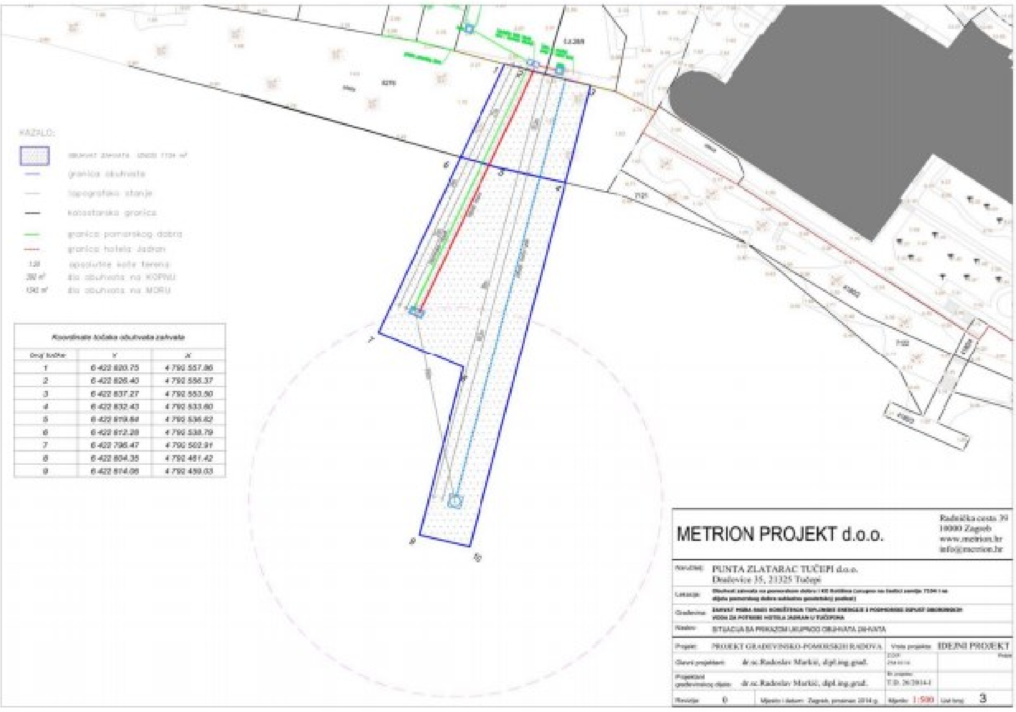


Figure 54 - Intervention of the planned project activities on land and sea

Rectors Palace in Dubrovnik has installed seawater heat pumps operating in cascade mode providing thermal water, heating, and cooling for the building. Installed capacity is 6x72 kW (50/45 °C) for heating and 6x70 kW (30/35 °C) for cooling purposes. The system is installed near the sea in a building that is a monument of cultural heritage, making it self-sufficient and independent of fossil fuels. The basic elements are two heat exchangers supplying heating and cooling to the primary circuit of the heat pumps, six heat pumps, and a tank with 2000 litres of prepared water for consumers. The system is operating since July 2019. The engine room of the installed system is given in Figure 55.

Figure 55 - Heat pump installation in Rector's Palace

2.4 SWOT Analysis

Information gathered from BE potential evaluation and technology assessment are used to carry out a SWOT analysis on selected technologies for the pilot cases. Considered technologies are wave energy converters and seawater heat pumps, both applicable for urban coastal areas and ports. While carrying out the assessment, local specifics are considered including the existing regulative policy, potential for blue energy, and finally, potential impact and feedback from the society. The SWOT analysis is carried out for WECs, and seawater heat pumps separately, after which the most appropriate technology is proposed for further analysis.

2.4.1 Wave energy converters (WECs)

The main advantage that derives from the deployment of WECs is the utilisation of locally available resources. Also, they can be incorporated into existing or new, planned port infrastructure, i.e., breakwaters as already mentioned. Their deployment can boost up local jobs during the installation and maintenance work, simultaneously encouraging innovation in the field. The major weakness identified for WECs devices is a low energy potential, followed up by poor load capacity factor and non-satisfactorily level of technology readiness. Having in mind high investment costs, and unknown and unclear procedures for obtaining required permissions, there are significant drawbacks for the wider deployment of such devices. The current Levelized cost of electricity (LCOE) produced from WECs devices is around 45 ct€/kWh. At the same time, it is expected further reduction to 20 ct€/kWh by 2025, 15 ct€/kWh by 2030, and finally to 10 ct€/kWh by 2030, which would make it commercially competitive with other forms of RES. Figure 56 presents the visualisation of SWOT analysis for wave energy converters.

Strengths	Weaknesses
• The utilisation of locally available marine renewable energy resource • Estimated wave energy potentials are adequate for certain devices. • Adequate sea depths along the Italian coast for some of the wave converter technologies. • Presence of several commercial ports and marinas (especially in the central and southern Adriatic) that can host Oscillating water columns systems, Oscillating Body systems, and Overtopping converters. • Presence of artificial barriers for coastal protection that can host (or be replaced by) Overtopping converters or Oscillating wave surge converters. • Presence of wave monitoring buoys in certain areas. • Detailed data on wave potential was collected and processed by ENEA (the national research centre on energy). • The low visual impact of submerged (or partly submerged) devices. • Availability of certain port authorities and local administrations in supporting the development of these technologies.	• Low wave energy potential (very low in the north-eastern Adriatic Sea, higher in other sections), unsuitable for many devices. • The wave energy potential varies along the Adriatic coastline and is prone to seasonality. • Need for downscaling/adjustments for devices designed for areas with higher potentials. • Oscillating water columns systems generally need ad-hoc harbour structures and a deep seabed (only suitable in some port areas). • Low near-shore bathymetry, rarely exceeding 100 m within the first 20 km from the coast. • Low offshore bathymetry in certain regions (FVG, Marche and Abruzzo). • The high visual impact of certain devices. • Potential negative impacts on the marine environment to be further investigated. • Maintenance problems due to the salinity (causing corrosion), and biofouling. • Low capacity factor. • Technology still in the development phase (TRL 3-7) - Lack of adequate number of technologies having been tested and marketed • Difficulty in analysing costs and benefits of the selected technologies caused by

	the lack of data on their production capacities • High investment costs • Need for Environmental Impact Assessment while the process is unknown
Opportunities	**Threats**
• Presence of some innovative SMEs already working on Blue Energy and RES. • Diffused interest in Blue Energy among local communities. • Creation of local jobs for plants design, installation and maintenance. • Boosting innovation potential in the local and regional entrepreneurial systems. • Additional benefits of wave attenuators (reduction of coastal erosion). • Possibility to use energy from waves for self-consumption in port areas. • Possibility to include wave energy in regional energy plans that are being updated/drafted. • Possibility to include wave energy systems in port plans that are being updated/drafted. • Possibility to integrate wave energy converters in aquaculture plants for energy self-consumption. • Possibility to integrate wave energy converters with other RES. • Contribution to climate change mitigation - reduction of CO2 emissions and dependence on fossil fuels • Contribution to the achievement of the objectives of sustainable energy plans (SEAPs)	• Blue energy is generally not considered in national and regional energy policies (lack of interest and awareness by policymakers). • Unclear and lengthy permitting procedure, including Environmental Impact Assessment. • Overlapping competencies of permitting authorities, lack of communication among authorities involved in the permitting process. • Lack of awareness among public authorities in charge of projects evaluation/permitting. • Possible opposition by environmental associations, citizens and/or other economic sectors (fisheries, navigation…). • Climate change can induce modifications in the wave climate, reducing power production. • Problems with the inclusion in Marine Spatial Plans • Power production lower than the expected - higher payback period

Figure 56 - SWOT Analysis for WECs

2.4.2 Seawater Heat pumps

Seawater Heat Pumps are also analysed through SWOT analysis. Firstly, technology is fully developed and commercially available. Devices are highly efficient with COP between 4-5, converting one unit of electrical energy to 4 or 5 units of heat. This can reduce the CO_2 emission and dependence on fossil fuels, which is crucial for the island community. Operational costs are lower since there is no need for acquiring fuel.

Moreover, projects related to RES can get funding or loans with reduced interest. Finally, seawater heat pumps can be coupled with renewable energy sources improving the penetration of RES to the grid. Nevertheless, the installation of seawater heat pumps still requires higher investment costs compared to conventional solutions, which constrains wider deployment. Moreover, a building should be highly energy-efficient and have an advanced heating system to get the best from the device performance.

Strengths	Weaknesses
• The exploitation of a locally available renewable energy resource. • Consolidated, well-tested technology at the commercial development stage, availability of highly efficient devices. • Presence of coastline facilities (ports, waterfronts) that can be used as pilot locations for the deployment of the technology. • Adequate potential available (high in the northern Adriatic Sea) for both Open-loop ring with secondary circuit and Direct open-loop ring systems • Surface waters are excellent sources for water-water heat pumps, and the thermal source can be reached not far from buildings along the coast (savings on pipelines construction costs). • Deep waters are an excellent heat source for heat pumps due to their thermal stability. • Highly efficient devices	• Geothermal and hydrothermal energy is currently an underdeveloped sector in Italy. • During winter and autumn, the difference between average surface water temperature in the three sectors is higher than in spring and summer (more potential for heating than for cooling). • Maintenance problems due to the salinity (causing corrosion), and biofouling. • Deep waters exploitation shows criticalities due to the length of the pipelines. • Higher investment costs compared to conventional solutions. • Seawater heat pumps installation in existing buildings requires investments for energy retrofitting. • Potential negative impacts on the marine environment to be further investigated case by case.

• Lower operational costs compared to conventional technology • Reduction of CO_2 emissions and dependence on fossil fuels	• Higher investment costs compared to conventional solutions • A building should be highly energy efficient • Additional work is required on the cooling system • Complicated procedure for project implementation
Opportunities	**Threats**
• Creation of local jobs for plants design, installation and maintenance. • Possibility to include sea thermal energy systems in port plans that are being updated/drafted, and to integrate them in buildings/facilities under construction. • Possibility to integrate sea thermal energy with other RES. • Possibility to exploit brackish or deep salty aquifers, especially in FVG. • Potential to get funding or co-financing rate • Achieving energy independence • Protecting the environment, simultaneously enhancing the life-quality • Contribution to climate change mitigation. • Contribution to the achievement of the objectives of sustainable energy plans (SEAPs)	• Complicated permitting procedures, involving multiple public bodies and authorizations. • Possible opposition by environmental associations and citizens, especially for projects requiring public investments. • Sea temperatures variations due to climate change. • Problems with the maintenance (biofouling on parts exposed to sea environment) • Not being able to meet projected demand (auxiliary systems)

Figure 57 - SWOT Analysis for Seawater Heat pumps

Furthermore, to increase system efficiency, cooling should be introduced as well. However, cooling requires the installation of the cooling system, which requires additional investments. Finally, the unknown and unclear procedure for acquiring required permissions (i.e., concession, spatial planning) complicates the project implementation and may cause significant project delays. Also, there are some challenges regarding the biofouling and corrosion of the parts exposed to the sea environment, which may cause additional expenses and complicate the overall maintenance procedure.

3 Description of selected technologies and pilot areas

After the SWOT analysis was done, Seawater Heat Pumps is the most promising technology for the considered area. Also, WECs are showing potential for implementation, but with significant weaknesses in some areas at the time. Also, technology still hasn't reached a maturity level and commercial viability of operating, which constrains wider deployment now. Current projects are focused on prototypes and demonstration testing. However, with future improvements and cost reduction, WEC technologies are showing potential in areas with significant wave energy.

Seawater Heat Pumps are commercially available technology, already used on the Adriatic coast. Even though the investment costs are still higher and deployment procedure unclear, good efficiency and potential offer an excellent perspective for further deployment in urban coastal areas.

3.1 IRENA

Since the Adriatic Sea is not as highly energetic as the Atlantic Ocean and the North Sea and since this project has a more specific scope and it is focused on Blue Energy systems that are integrated into coastal infrastructure and built environment, the subject of the study was the analysis of Blue energy potentials for the western coast of Istrian County.

The Istria peninsula is the largest peninsula within the Adriatic Sea. It is located at the head of the Adriatic Sea between the Gulf of Trieste and the Kvarner Gulf. Therefore, its natural conditions are dominated by the presence of the Adriatic Sea and by the vicinity of the Ucka mountain range. Consequently, the Istria peninsula has different micro-climates that differ significantly from each other. Four micro-climate regions can be identified, namely central Istria with a continental climate, the northern coast of Istria with a sub-Mediterranean climate, the western and southern coast with a Mediterranean climate, and the eastern coast with a sub-Mediterranean climate and open sea influences. Only the natural conditions related to the western coast of the Istria peninsula were addressed including the bathymetric data, wave and wind climate, and properties of the sea current.

The area of Western Istria includes four towns and five municipalities (arranged in order from north to south):

- **City of Umag**
- Municipality of Brtonigla
- **City of Novigrad**
- Municipality of Tar-Vabriga
- **City of Poreč**
- Municipality of Funtana
- Municipality of Vrsar
- **City of Rovinj**
- Municipality of Bale

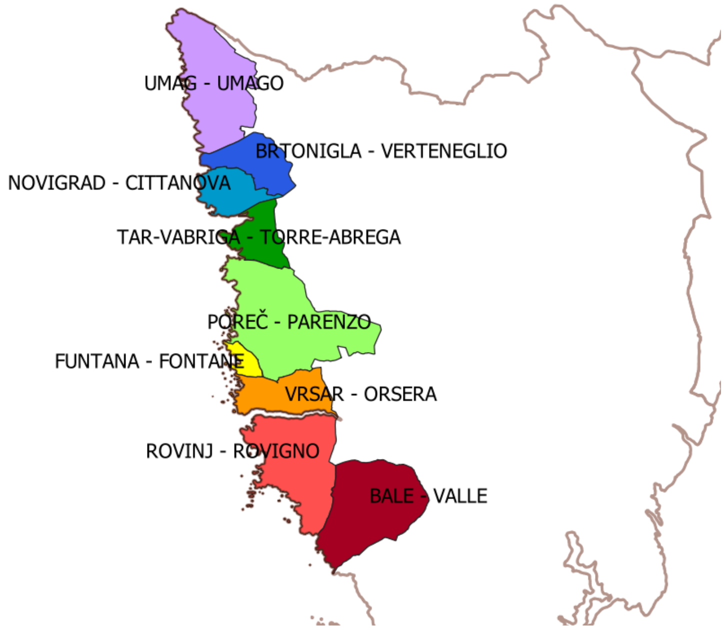


Figure 58 - The area of Western Istria

Based on the analysis, the total annual energy consumption in the sectors of buildings, public lighting, and transport in the analysed cities/municipalities of Western Istria in 2019 amounted to 706.112,03 MWh, where 79.93 % of total energy consumption refers to the building sector. Given that the building sector accounts for the largest consumption in the analysed cities and municipalities of Western Istria, it can be concluded that the implementation of high-efficiency heating and cooling technologies can greatly affect the reduced total energy needs. In addition, the implementation of high-efficiency heating and cooling technologies is favoured by the fact that in the building sector in the analysed area 10,98% of total annual consumption refers to the use of fuel oil, and 0,86% to the use of LPG. These fuels are environmentally unacceptable, and their use should, wherever possible, be minimized or eliminated.

Therefore, as a solution to the described problem, two technologies were analysed: the technology of using sea thermal energy and the technology of using wave energy. In agreement with the client, the City Palace, at the address: Obala Marsala Tita 5, in Poreč, was selected as a pilot area for assessing the potential of the implementation of these technologies. The reasons for choosing this building are the proximity to the sea, the use of fuel oil as an environmentally unacceptable energy source and the already installed fan coil units as heating/cooling bodies.

The technology of using sea thermal energy includes the use of a seawater heat pump as a source of heat and cooling energy. By implementing the mentioned system for the selected pilot area, it is possible to achieve savings of HRK 29.694,27 per year and a reduction of CO_2 emissions in the amount of 61,17 tons/year. The total amount of the investment is approximately HRK 795.000,00 with a simple payback period of 26,8 years.

Parameter	Value
Population [8]	208 109
Area, km²	2813
Population density, people/km²	74
Gross domestic product, in millions HRK(EUR) 2015 [8]	19.999,7 (2689)
Gross domestic product per capita, HRK(EUR) 2015 [8]	96102 (12922)
Total primary energy supply, PJ 2015	19,9
Total electricity consumption, GWh (2015)	757,7
Electricity production TE Plomin 1, GWh (2015), [10]	794
Electricity production TE Plomin 2, GWh (2015), [10]	1441
Total electricity production TE Plomin 1 & 2, GWh (2015), [10]	2235

Figure 59 - Main statistical indicators for the region of Wester Istria

Considering the maximum specific wave power of the pilot area in the amount of 0,219 kW/m, a techno-economic analysis of the technology of using wave energy was performed, i.e., the installation of a system with an energy converter in the breakwater - REWEC. Based on the stated potential, the annual production of electricity for the needs of the pilot area amounts to 129,118.67 kWh, with a total investment cost of HRK 2.736.000,00 and a payback period of 21 years. The main reason for the obtained results is the small specific wave power of the pilot area.

Tidal energy

Tidal power was analysed for Miljski Bay, Koparski Bay, Piranski Bay, Mirna port, Limska Draga bay, Puljski Bay, Mudulin Bay, Raški Bay and Plomin Bay. The potential energy of one tide is estimated to be 5664 MJ. As there are two high tides per day the total potential energy is estimated to be 11328 MJ or 0,131 MW in a day. Assuming the power conversion efficiency of 30%, we can estimate the available power to be 39,3 kW per day or 344 MWh per year. The average yearly electricity consumption per person in Istria is 3641 kWh. Therefore, from the tidal power plant, the electricity for the need of only 95 people would be generated.

Wave Potential

The significant wave height for the sea around the Region of Istria (North Adriatic) is 0,4-0,5m, see Figure 60. The seas are calm for 30-40% of the time, therefore no energy production would be possible, see Figure 61.

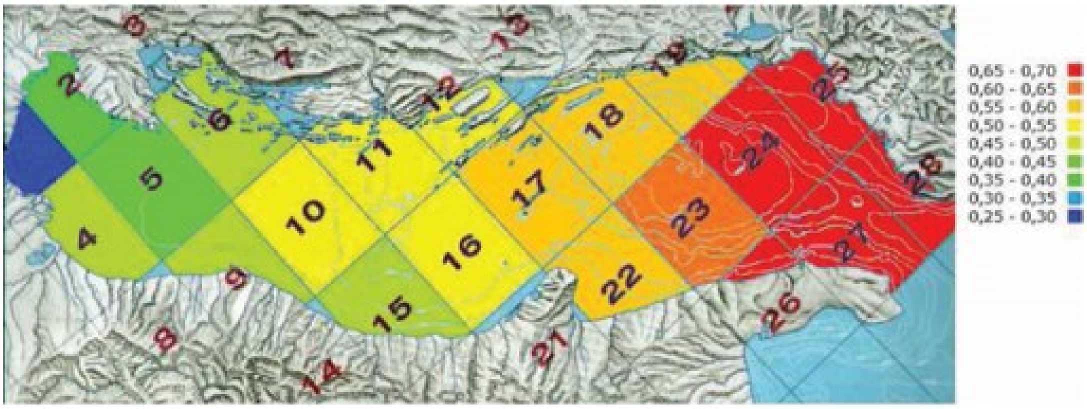


Figure 60 - Mean annual significant wave heights per quadrant in the Adriatic Sea

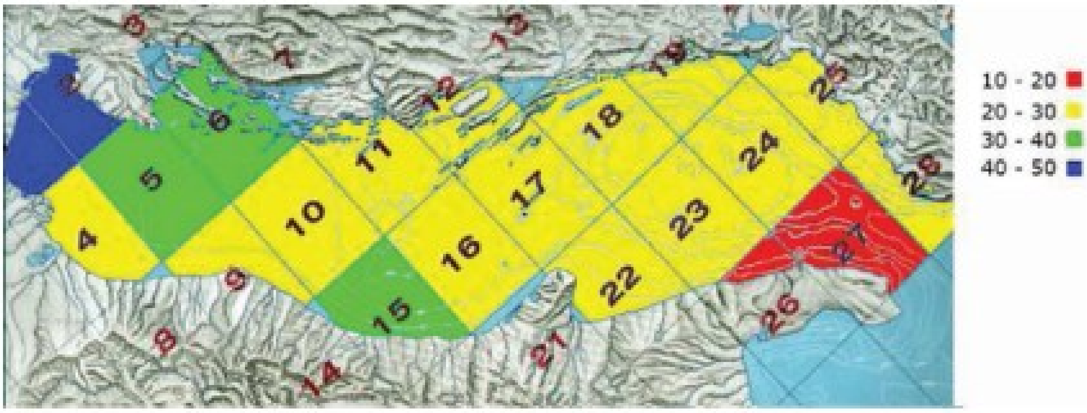


Figure 61 - Time percentage of calm seas in the Adriatic Sea

According to experts the borderline value of 25 to 30 kW per linear meter of the wave front is necessary for a wave power plant to be economically viable. The wave energy is then estimated to be between 0,26 and 0,39 kW/m. This value is far less than 25 kW/m, which is estimated to be economically viable.

Thermal Energy Potential

The monthly surface temperatures for the northern and southern Adriatic Sea are given in Figure 62. The seawater temperature as a function of depth along the east Adriatic is provided in Figure 63. Note that this was for July 2008.

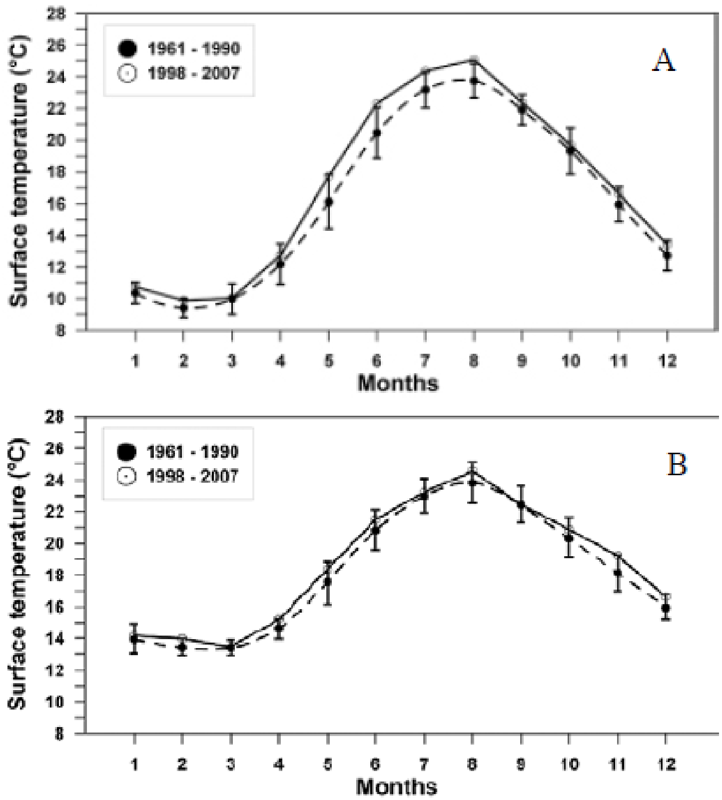


Figure 62 - Average temperature values of the (●)1961-1990 and (○) 1998-2007 periods for the open Adriatic Sea surface waters: (A) Rovinj RV001 (northern Adriatic) and (B) Stončica (southern Adriatic)

The average seawater temperature is below 16 degrees at more than 40m depths. Moreover, it is reasonable to assume the ground seawater temperature will have lower temperatures at even lower depths as it is not directly affected by the sun.

The average temperatures in Pula are 4,6 to 26,7 degrees Celsius. Therefore, the seawater temperature of 12 to 14 degrees has a good potential for heating (10 degrees more than minimal average) and cooling (10 degrees less than maximum average).

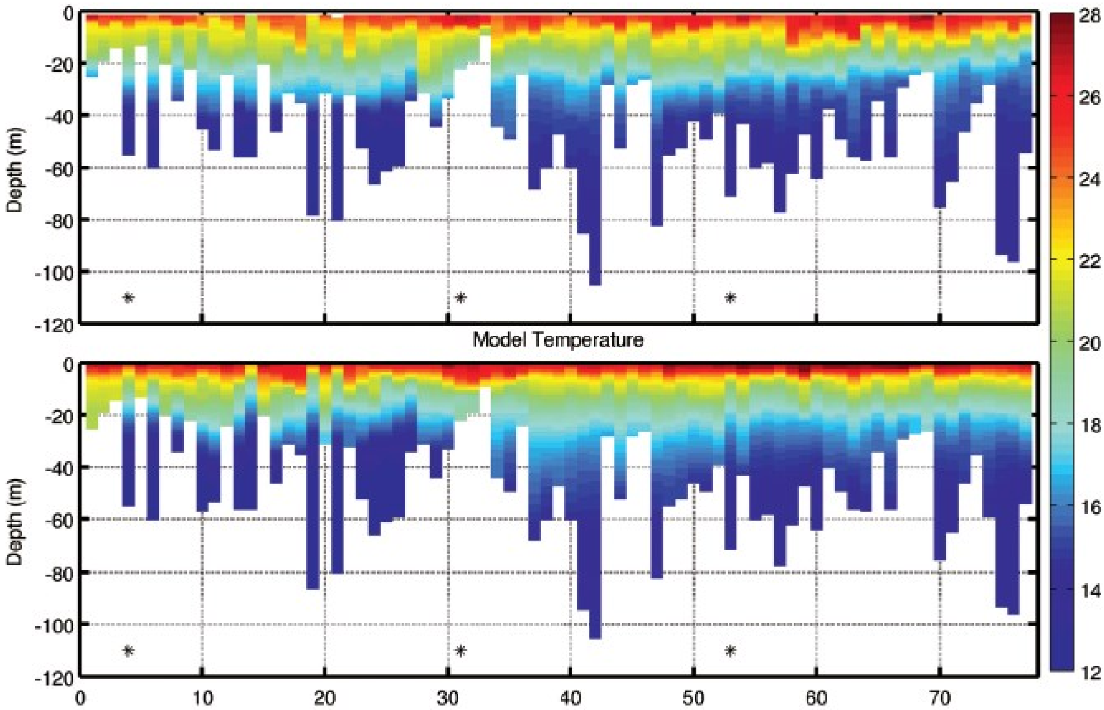


Figure 63 - Temperature data for July 2008 cruise based on CTD observations and model prediction. The stations are at the x-axis and numbers correspond to one in Figure 62 (sorted from North – station 1 to South – station 77). Observations 4, 31 and 53 with a star are near rivers Rjecina, Zrmanja and Cetina

3.2 SDEWES Centre

This section is dedicated to an economic assessment of seawater heat pumps which are selected as the most appropriate technology for the Cres-Losinj archipelago. The precise investment costs are often not available, especially if the project is carried out with private investment. The available costs for the installation of seawater heat pumps are available for projects which are carried out under the funding of some national or European projects. Therefore, the information provided in Figure 64 is related to investment costs applied for bigger systems (>100 kW), and as such are not fully representative for this case. Nevertheless, it is interesting to compare the payback periods for Hotel Bernardin and The Orthopaedic and Rehabilitation Hospital. Hotel Bernardin used the ESCO model of financing, where the private company took care of all investment costs, and now acts as an energy supplier. The expected payback period is less than ten years. On the other hand, the Hospital investment costs were subsidized by the European funding with around 1 million €, which implies that only 200 000 € was financed from own sources. If the subsidy is ruled out, and own investments of 200 000 and 500 000 € are observed, expected payback is only three years longer for the case of Hotel Bernardin. The reason for this might be in renovation which was carried out in case of Hotel where significant energy savings are achieved. In the case of the Hospital, there were no significant modifications to existing infrastructure, implying that the system is highly efficient in the case of renovated buildings. In general, the price of the system depends on local geographical and morphological characteristics. This includes the distance from a sea, need for drilling, additional infrastructural work and similar. Moreover, the size of the system affects the price significantly. To minimise the costs, a building should be energy efficient, with precisely determined heat load and annual heat demand to avoid potential oversizing of the system.

Site of installation	Heating/cooling capacity installed [kW]	COP/EER	Yearly produced heat/cold [kWh]	Investment [€]
Faculty of maritime studies and transport - GOLEA, Nova Gorica [25]	66 / 55	3.26 / 3.02	91 000 / 75 000	~30 000
Grand Hotel Bernardin – Portorož [25]	1000	Not available	3 000 000 for heating only	500 000 (payback 10 years)
Rectors Palace Dubrovnik [26]	430 kW for both heating and cooling	Not available	Not available	510 000
Hotel Parentium, Poreč [27]	Cooling 692 x 2 Heating 795 x 2		723 000 for both heating and cooling	2 000 000 (payback 6 years)
The Orthopedic and Rehabilitation Hospital „Prim.dr. Martin Horvat“ [26]	700		800 000 for heating only	1 200 000 (payback 7 years)

Figure 64 - Most significant projects on the Adriatic coast up to now

Sales of ground-coupled heat pumps have stabilized around 100,000 units. However, the size of installed systems is increasing as they are often used for larger commercial buildings and industrial applications. When it comes to heat pumps replacing direct electric heating, a heat pump installation results in the immediate reduction of operating cost because of much higher seasonal energy efficiency. A heat pump with an SPF of 4 would reduce the heating cost to 25%. Even a heat pump with an efficiency of only 2.5 would result in 60% savings of operating cost, usually enabling the investor to overcompensate the higher investment cost over the lifetime of the installation, if the electricity price is not too high [25].

The investment cost for the case of seawater heat pumps is divided into investment costs (CAPEX) and operational costs (OPEX), and the cost of dismantling. Details are given in Figure 65.

CAPEX	OPEX	DISMANTLING
A1 cost of system design (often hidden)	**B1** fuel	
A2 administration cost: permits, application procedures, etc.	**B2** maintenance, insurance	
A3 cost of the product or system including the tank	**B3** competitive advantages and disadvantages affecting B1 and B2: subsidies for the energy used, taxation of the energy carriers preferred electricity tariff compensation for demand-side flexibility	**C** cost of refurbishment, exchange or dismantling
A4 installation cost		
A5 financial advantages based on the investment cost: loans, grants, tax reductions, consulting services etc.		

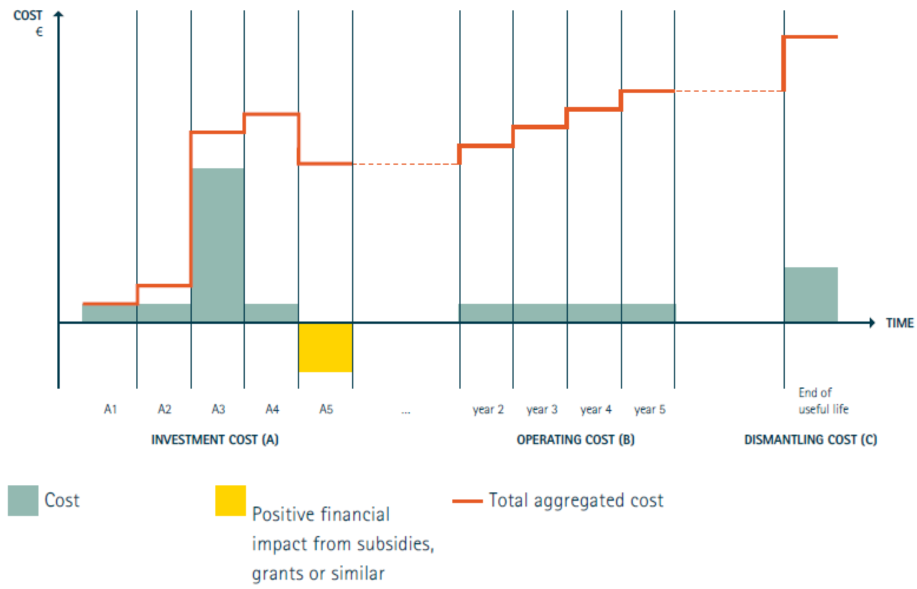


Figure 65 - Identified costs regarding the deployment of a seawater heat pump

Subsidies and preferential loans might be crucial instruments for the deployment of such devices, especially when it comes to private households. In the last few years in Croatia, The Environmental Protection and Energy Efficiency Fund (EPEEF) is a governing body for tenders and subsidies regarding the RES. For the case of private owners of households, in the two last calls, the rate of financing was determined depending on the location of installation and the maximum amount that can be granted. For the case of the Cres-Losinj archipelago, this is the *second group of islands*, for which is possible to get 60% of funding or a maximum amount of 33 750 HRK [28]. Grant is predominantly focused on acquiring technology, while the costs of project documentation are mainly on the investor. Allocated funds in the grants were 12 and 11 million HRK, respectively [29]. For 2020 in the scope of Energy refurbishment, for citizens, it is possible to get up to 48 750 HRK for the installation of the heat pumps [30]. Noticed problems with subsidies lie in the fact that they are intended for the replacement of old heating/cooling systems. At the same time, it is not possible to get funding for new projects with the implementation of seawater heat pumps.

The seawater thermal energy potential in the Cres-Losinj archipelago

After the SWOT analysis was done, Seawater Heat Pumps are selected as the most promising technology for the considered area. As can be seen, WECs have pronouncedly more weaknesses at the time, compared to the internal strengths. Also, technology still hasn't reached a maturity level and commercial viability of operating, which constrains wider deployment now. When all mentioned here and in the previous section is considered, it is evident that seawater heat pumps are the optimal and feasible technology, and therefore selected for further analysis.

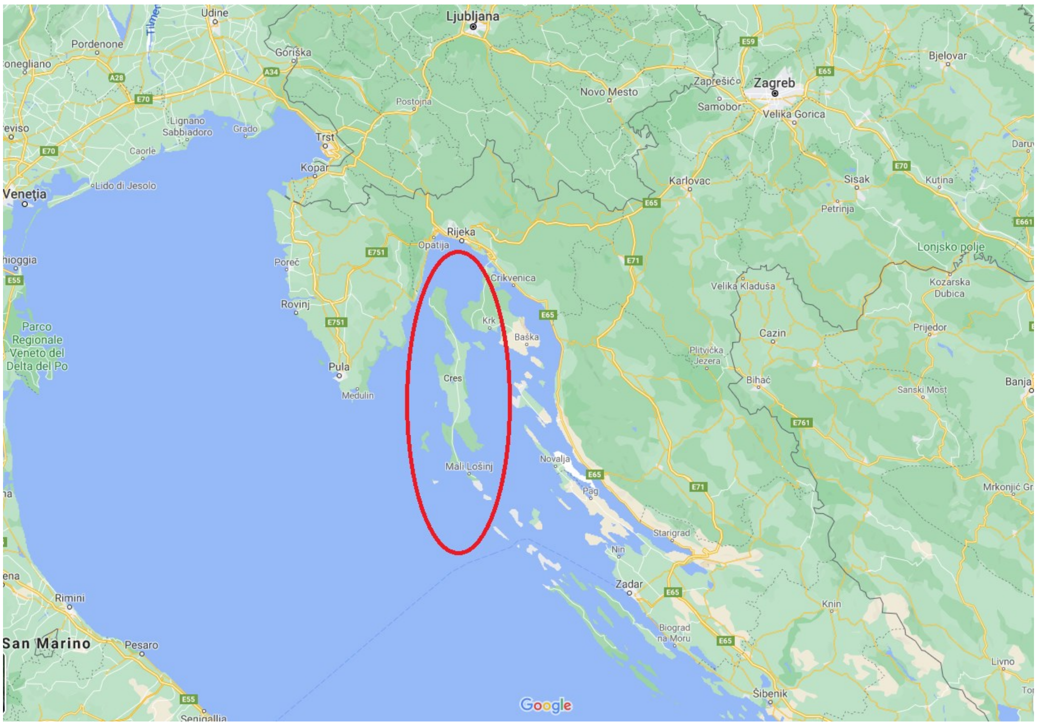


Figure 66 – Cres-Losinj Archipelago (Google maps)

For SWHP the temperature of seawater is the most important fact - The constant temperature of seawater results in a higher coefficient of performance (COP). The average seawater temperature for the Adriatic Sea is between 11 and 24 °C during the year. Figures 67 and 68, present the average sea temperature for the Cres and Mali Losinj, and temperature varies between 11 and 26 °C during the year.

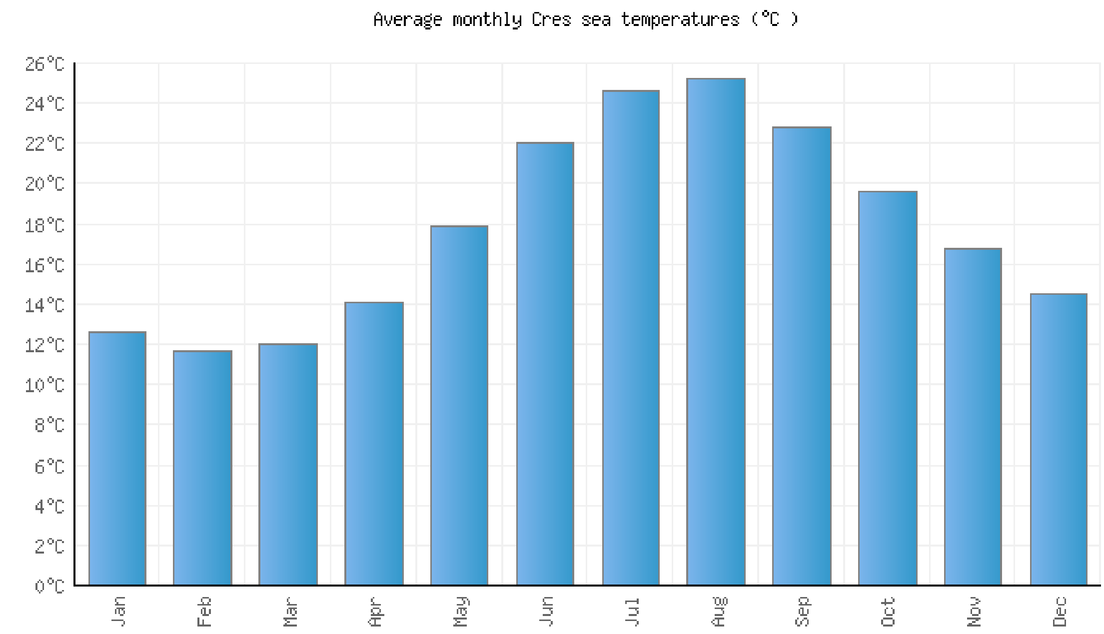


Figure 67 - Average monthly sea temperatures for Cres [12]

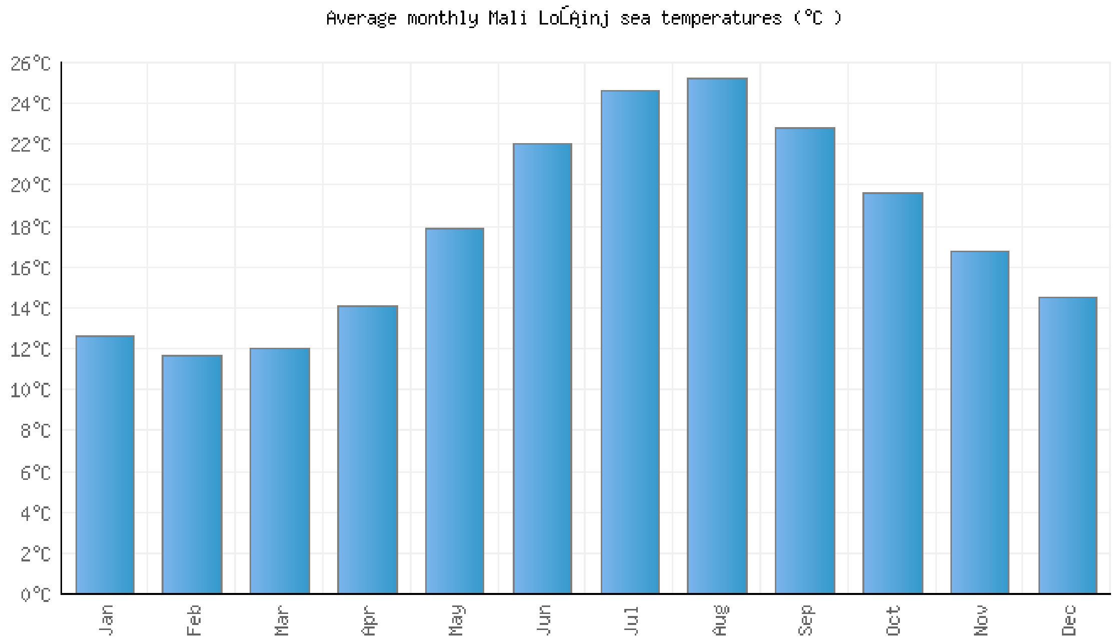


Figure 68 - Average monthly sea temperatures for Mali Lošinj [13]

3.3 DURA

Analysis of the potential for the use of thermal energy of the sea in the contact area (buffer zone) which mostly includes the historic urban landscape of Dubrovnik, including the historic areas of Konavle, Boninovo and Gruž west of the city centre, Ploče and St. Jakov to the east, and the peak zone and the southern slope of Srđ.

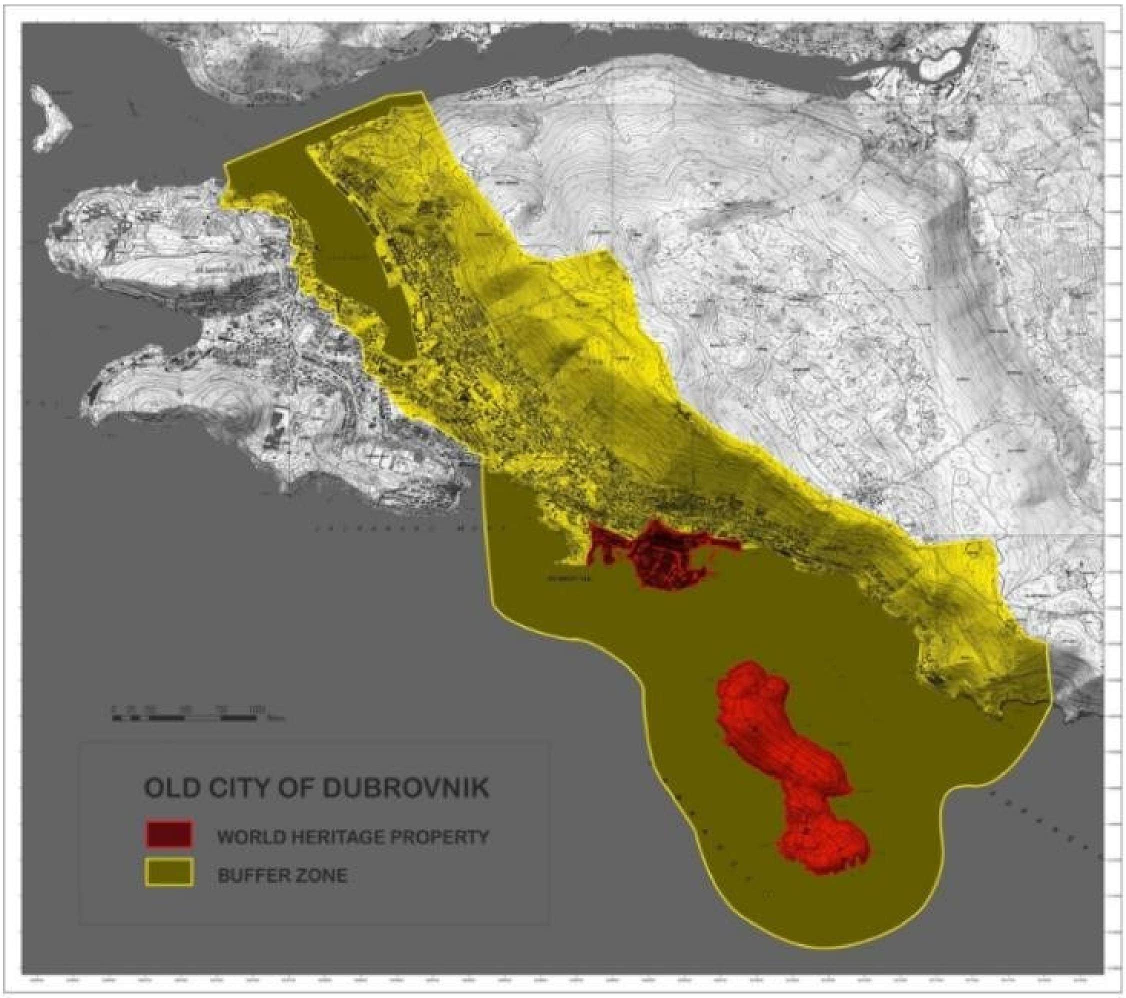


Figure 69 Targeted area

The study covers the possibility of using sea energy for heating and cooling buildings in such a way that seawater is directed into the heating system. In the heating regime, the seawater would be deprived of thermal energy and then transported for energy to the heating system of buildings. In the cooling mode, heat energy is transferred to the seawater and in this way the seawater is consequently heated.

The city of Dubrovnik is a coastal city located along the coast and was built in different phases over several centuries, while most of the urban ensemble is protected as a cultural urban zone that needs to be preserved in its original state. Some buildings are protected as immovable cultural property, which additionally sets the technical conditions for the selection of models and equipment for the application of marine energy.

The entire construction zone of the city of Dubrovnik is in an earthquake area with occasional earthquakes that have significantly damaged the city centre throughout history. One of the largest earthquakes was in 1667, which damaged most of the buildings, and an earthquake of this type can be repeated. The potential danger of stronger earthquakes further limits the possibility of applying certain technologies for the use of blue energy.

Blue energy for heating and cooling with seawater includes the capture of seawater and then the direction of seawater to the central heating and cooling engine rooms. The intention is to analyze the possibility of using blue energy for the entire city centre. Considering a large number of different buildings and the coastal concentration of buildings, it is necessary to carry out the seawater intake at several locations along the coast, so it will be possible to cover the entire city zone.

To analyse the available technologies for the use of thermal energy of the sea and the selection of technologies that have the potential for installation in the subject area of Dubrovnik. The COASTENERGY project is focused on the use of sea heat in the coastal area, ports and especially within the existing and future infrastructure with a special analysis of the potential of heat pump technology in this way, especially considering future projects (infrastructure, etc.) provided by spatial plans and other relevant documents of cities and municipalities belonging to the subject area of Dubrovnik.

TECHNICAL DESCRIPTION OF WATER-WATER HEAT PUMP

The climatic conditions prevailing in Croatia allow the use of reversible heat pumps for heating and cooling the building. With the help of the device, it can be reliably heated even at the lowest outside air temperatures that can occur in the micro-location of the city of Dubrovnik and its surroundings, i.e., up to -10 ° C. For space heating and cooling, the so-called reversible heat pumps can switch the operating mode from heating to cooling and vice versa as needed with a very low time to change the operating mode of the system.

The installation is intended for use:

- water-to-water heat pump
- installed in the engine room of the building
- suction and absorption well located on the plot
- or connection to a public water distribution pipeline
- the primary use of cooling and heating devices and domestic hot water heating

The basic energy source of a building is the energy of the environment, which is transformed into the required energy form by applying transformation technologies. Electricity from the grid is used to run a heat pump that simultaneously draws on energy that has accumulated in the environment. The devices are used in combination with work with renewable heat sources. Accumulated solar energy in the environment is used as a source of energy for heating buildings. The heat pump then converts the two input forms of energy into a useful form of thermal energy that accumulates in the heating system. Heat pumps convert electricity into heat or cooling energy and have an SPF system factor in the range of 2.5 - 5.5, depending on the type of heat pump that has a COP factor of 4.5 - 5.5. In cooling mode, energy is transferred from the building by a heat pump to the environment. The basic principle of operation of a heat pump is to take 1 kW of electricity from the electricity grid and 2-4 kW of renewable accumulated energy from the environment, while the sum of these energies or 3-5 kW of heat energy is injected into the building. By using a green electricity tariff or photovoltaic energy, the system becomes 100% renewable.

A centralized system is envisaged that maintains the required microclimatic conditions throughout the year. The water-to-water heat pump has a mean annual efficiency factor above SPF 4.5 in temperate geo-climatic areas, while the device factor itself achieves a COP value of 5.5. Concerning heating using a gas system or natural gas, savings of 50-60% are achieved depending on the geo-climatic of the building location. Compared to natural gas heating, carbon dioxide emissions of CO_2 are also reduced by 90%, which is a sufficient reason for the application of these renewable systems. The nominal operating temperature is around + 10 ° C of groundwater, while at outdoor temperatures of -20 ° C there is a small drop in groundwater temperature, and the device itself could operate down to -25 ° C with proper sizing and sufficient groundwater depth. Compared to classic dual heating and cooling systems, space savings are also achieved because the unit has integrated heating and cooling and facilitates system maintenance, which reduces the overall investment.

3.4 University of Camerino

The eastern border of the Marche region has 172 km of coast on the Adriatic Sea. These 172 km are divided into 11 Physiographic Units, in turn, divided into 64 Coastal Management Units.

Figure 70 - Marche region (Google Earth)

The wave energy potential in the Marche Region

For the wave motion, it is possible to divide the region into 2 sectors. The northern one is from Gabicce Mare to the promontory of Conero with NW-SE 128°N orientation, the southern one is from the port of Numana to the mouth of the Tronto river, with an approximate 160°N orientation.

Because of the morphological characteristics of the coast and the positioning of the wave buoys, to calculate the wave energy potential of the two sectors, data are collected from two different buoys of the ITALIAN WAVE NETWORK. For the northern sector, the data were referred to as the wave buoy of Ancona, while for the southern sector the data were recorded by the buoy located off the coast of Ortona.

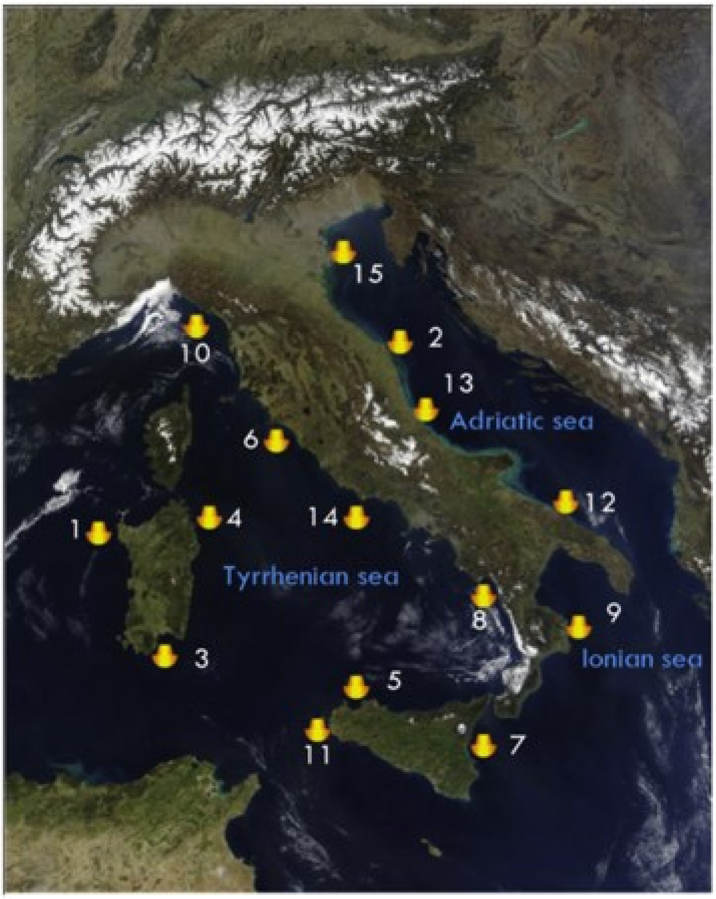


Figure 71 - Location map of the IWN wave buoys (n. 2 Ancona buoy – n. 13 Ortona buoy)

The data collected by the buoys, which are positioned in the offshore area, show the following annual mean characteristics: for the Ancona buoy, the mean wave has an H_0 of 0.76 meters with a Tp of 6.1 seconds and a power of 3.11 kW/m; for the Ortona buoy, mean wave features are an H_0 of 0.71 m with a Tp of 4.2 and a calculated power of 1.14 kW/m.

Since the data recorded by the buoys are collected in the offshore area, the dataset includes all wave directions, including those that are formed by winds with directions that go from the coast to the open sea. Therefore, the wave data detected by the buoys can lead to an incorrect calculation of the potential in the nearshore/coastline area, since these data are not “filtered”. When calculating the average wave power, it is more appropriate to subtract from the registered waves those moving from the coast towards the open sea, which has a reduced fetch and less time to increase their height and period. In this way, the average wave power increases and therefore results higher than expected.

Furthermore, as shown in the figures below (Dykes et al 2009), the storms of Bora winds produce a different effect on the Italian Adriatic coasts than the storms caused by Scirocco winds coming from the south.

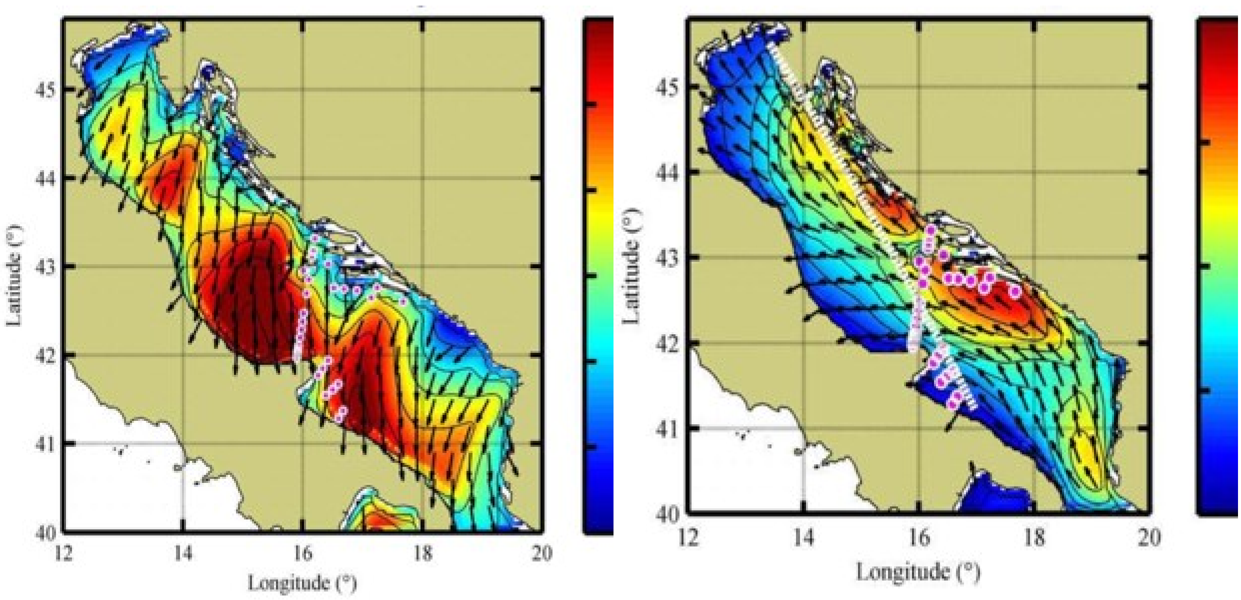


Figure 72 - Wave height and direction in the Adriatic (Dykes et al 2009)

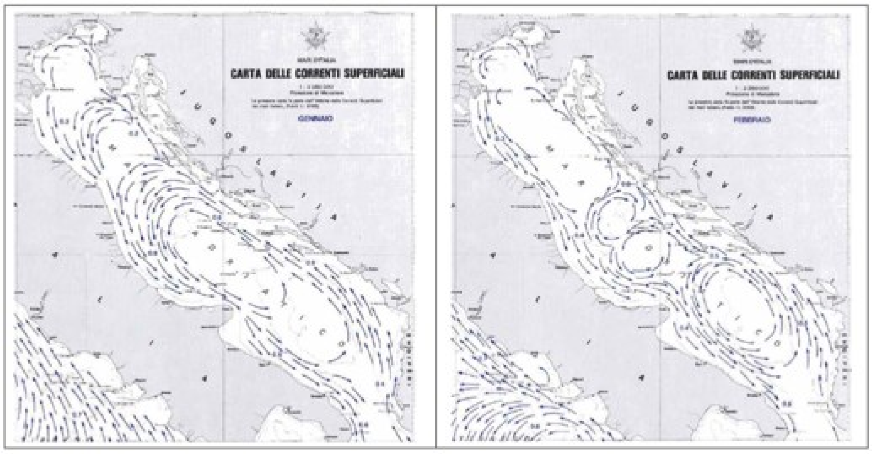
For these reasons, calculations were carried out considering only the waves directed towards the coast.

In this way, it was possible to recalculate the average characteristics affecting the wave energy potential: for the northern sector, the mean wave features are an H_0 of 0.89 meters with a Tp of 6.27 seconds, and an average potential of 4.35 kW / m, while for the Ortona buoy those features are a H_0 of 0.77 m and a Tp of 4.58, for an average power of about 2.9 kW / m.

The seawater thermal energy potential in the Marche Region

Aldo from the thermal point of view, the Adriatic Sea section of the Marche region can be divided into two sectors, the northern and the southern ones.

This is due to the currents occurring in the Adriatic, which create an anti-clockwise vortex around the centre of the region. This vortex mixes the cold waters from the northern Adriatic and the warm waters that come from the east from the Mediterranean and the Ionian Sea. For this reason, the sea temperatures at the surface level show low-temperature excursions between the two sectors. The data obtained by the RMN (Rete Mareografica Nazionale) show a difference of 1°C between the mean temperatures recorded in the survey station located in Ancona in the northern sector and the one located in San Benedetto del Tronto in the southern sector.



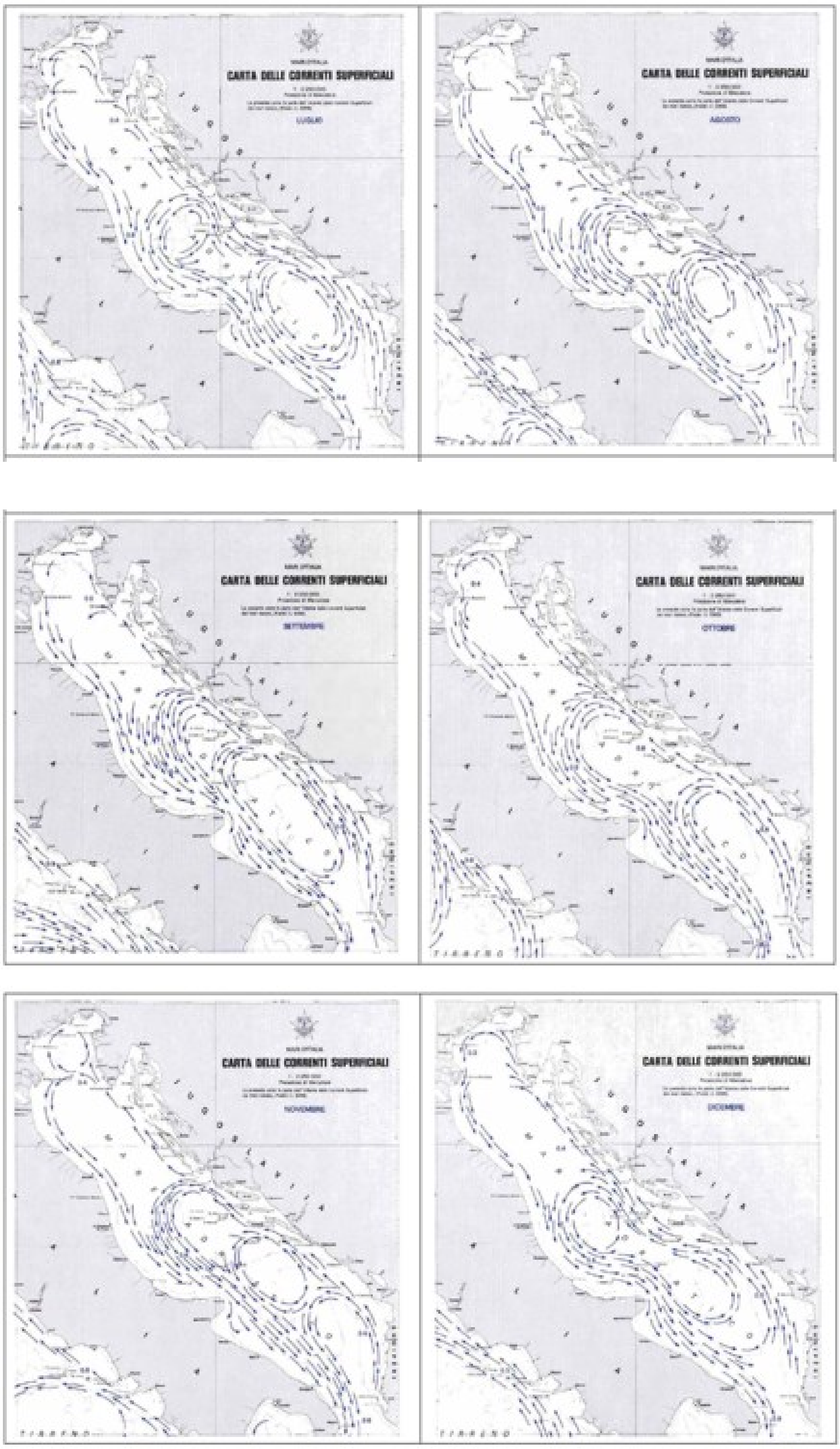


Figure 73 - Map of surface currents (Atlas Source of the surface currents of the Italian seas – Istituto Idrografico della Marina)

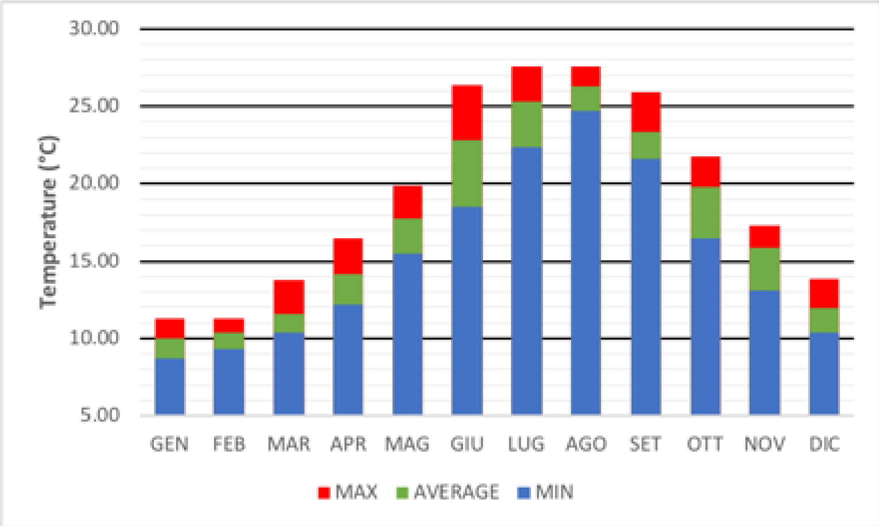


Figure 74 - Annual sea temperature variation in Ancona

The chart above shows the data relating to the Ancona station and the temperature changes between the different periods of the year. The minimum temperatures are in January with an average of 10 °C, with the minimum recorded at 8.6 °C, on the contrary, the maximum temperature is recorded in August with an average of 26.27 °C and a peak of 29 °C. This means that at the surface level the annual temperature range is over 15 °C.

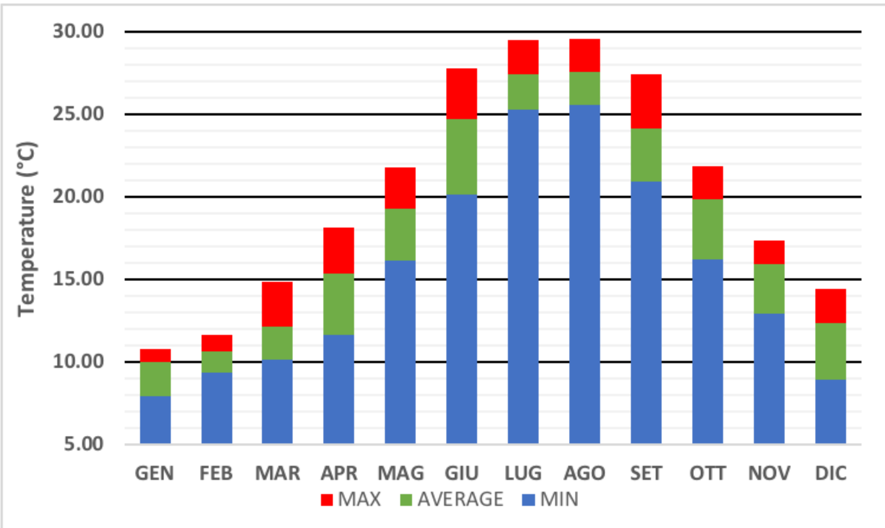


Figure 75 - Annual sea temperature variation in San Benedetto del Tronto

The figure above shows the data recorded in San Benedetto del Tronto, where the minimum average temperature is in January (9.69 °C), with a recorded minimum of 7.95 °C, while the month with the highest average temperature in August, with 27.59 °C and a peak of 29.60 °C. Despite the presence of the mouth of the Tronto river - a 122 km long river that has abundant flow rates between autumn and spring while this is low or zero in summer -, the Tronto waters do not have a significant influence on the surface water temperature trend.

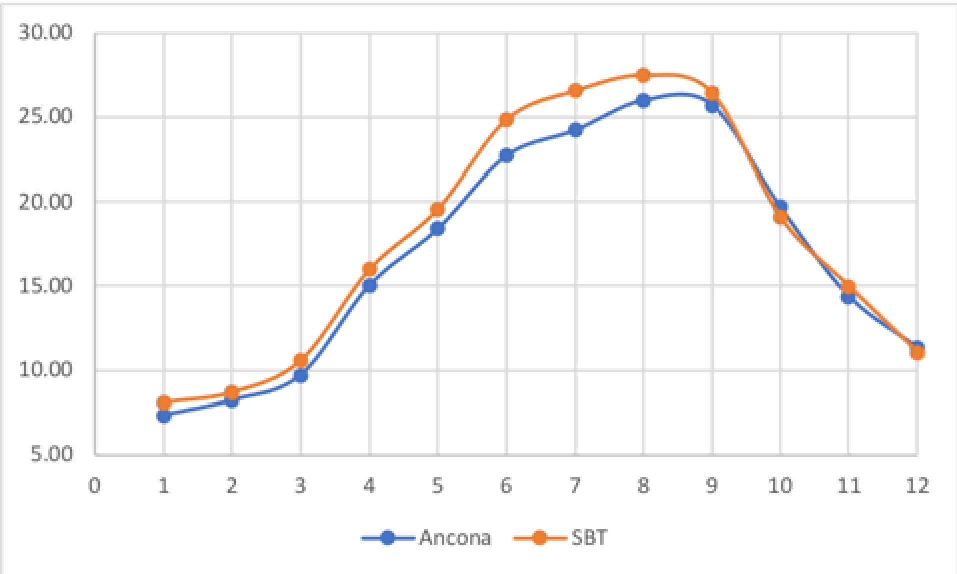


Figure 76 - Comparison between Ancona RMN station (blue) and San Benedetto del Tronto RMN station (SBT-orange)

Comparing the annual temperature trends between the two stations, Ancona, and San Benedetto del Tronto, the above chart shows that the general trend is very similar, with the only difference in temperature of 1°C between the data recorded in Ancona and those recorded in San Benedetto.

Selected Technologies

The technologies that have been selected for the coastal area of the Marche region include both wave energy conversion systems and systems for exploiting the marine thermal gradient utilizing heat pumps.

Wave energy converters

The selected WECs are of three different types: oscillating body (OB), overtopping converters (OTD) and oscillating wave surge converters (OWSC). The reasons why these devices have been selected lie in their functioning and their physical features. These devices can be integrated with existing structures or solve additional problems related to the erosion of the coasts while supplying energy.

The **Wave clapper** has been selected for the OB category. This system draws energy from wave power throughout uniquely shaped floaters, which rise and fall with the up-and-down motion, lifting force, change of water level, hydraulic air lock, and incident flux of waves. The floaters are attached by robust arms to any type of structure, such as breakwaters, jetties, piers, poles, and floating and fixed platforms. In the Marche region, there are nine harbours, and this conversion system would be perfectly integrated with port structures.

The **Wave Dragon** system has been selected for the OTD category. It is a floating, slack-moored device based on the principle of overtopping. The machine consists of two symmetrical reflecting wings that focus the waves on a ramp. Behind, the overtopping water is collected and driven to a series of Kaplan turbines, thus converting the difference of potential energy into electricity, like in a hydropower plant. The structure of the Wave Dragon could integrate or replace, the current parallel emerged dams that are present in different sectors of the Marche coast. In this way, the device would guarantee both protection to the section affected by erosion and the production of energy. However, the Wave Dragon would need a downscaling to be suitable in our region.

For the OWSC category, two devices were considered: The **Oyster** and the **Waveroller**. Both convert ocean waves to electricity by a flap that moves and absorbs the energy. The difference between the two devices is the position of the alternator, which is separate from the converters and positioned onshore for the Oyster, while it is integrated into the device for the Waveroller. Both devices have an anti-erosive function since they dampen the wave motion and decrease its power, thus limiting erosion in the sectors behind them. For this reason, they could either replace already existing submerged dams or be installed to protect coastline sectors that are currently without anti-erosion systems.

Seawater thermal conversion – heat pumps

To use seawater as a thermal source it is necessary to divide it into two categories, surface, and deep waters, both of which have advantages and disadvantages related to stability/instability of the thermal source and ease/difficulty of exploitation.

Surface waters are thermally unstable but, thanks to the thermal inertia of the water and the large basins, these are excellent sources for water-water heat pumps. Their advantage is in reaching the thermal source not far from buildings along the coast, while the disadvantages are represented by the salinity (causing the corrosion of the materials), and by the filtering of the suspended material. For these reasons, the use of surface water must be accompanied by an analysis of water quality and consequently an accurate design of the entire system, as well as ensure compliance with bureaucratic procedures to obtain the necessary authorizations.

The **deep waters** maintain almost constant temperatures throughout the year. These are excellent heat sources for heat pumps. Their temperature varies from 10 to 15 degrees. If the sampling point is at an adequate depth, the temperature variations on an annual basis are irrelevant. Their advantage is, therefore, the thermal stability of the source, while the disadvantage is linked to the depth at which the waters will have to be collected and therefore to the length of the pipelines.

3.5 University of Udine

The low wave energy potential in Friuli Venezia Region

The wave energy potential of the northern Adriatic Sea is very low, especially in the Friuli Venezia Giulia region as shown in the figure below. More in detail, the sea in the region has low wave power and wave height. To have high performance or at least a significant level of profitability, it is necessary a wave power between 8 and 15 kW/m, a wave height of at least 1.2 m, and a wave period of at least 4 s. Conversely, the northern Adriatic Sea is characterized by a wave power between 0.04 and 1.31 kW/m, a wave height between 0.328 and 0.488 m, and a wave period of 2.85 –3.20 m/s. The results are summarized in the table below.

The low wave energy potential of the northern Adriatic Sea is confirmed by the analysis of the blue potential carried out within the Maestrale project – Interreg Med.

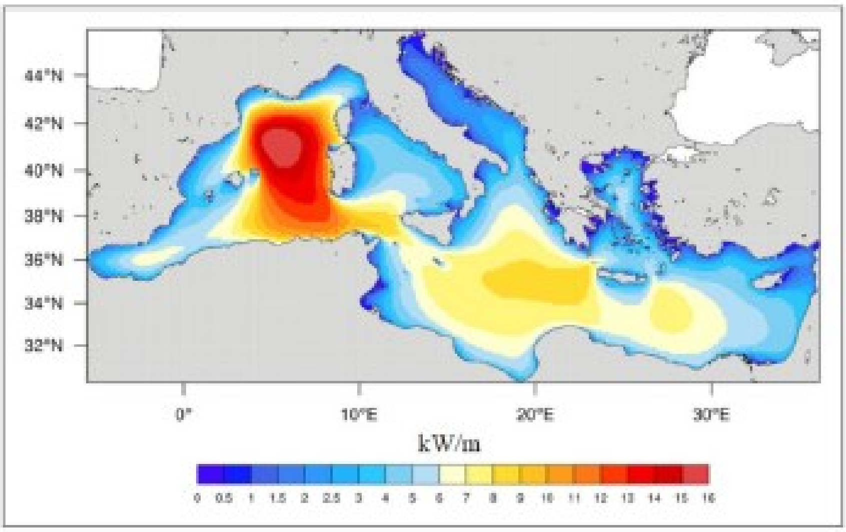


Figure 77 - Map of average potential energy in the Mediterranean

Blue energy source	Data	Minimum requirements for profitability
Wave power	0.04 –1.31 kW/m	8 –15 kW/m
Wave height	0.328 –0.488 m	1.2 m
Wave period	2.85 –3.20 m/s	4 s

Figure 78 - Data on the blue energy source of the northern Adriatic Sea

The geothermal and sea thermal resource in the Friuli Venezia Giulia region

As stated, before the wave energy potential of the northern Adriatic Sea is low. Therefore, we take into consideration other sources of blue energy, particularly the geothermal source.

In the region there are several historical and current evidence of geothermal sources that are listed below:

- the Roman Baths of Monfalcone, fed by a singular source that flows spontaneously from the limestones with a T of 38-40 °C;
- the waters coming from the artesian aquifers at 340 m of depth in the Grado Lagoon (Val Noghera-Isola di Morgo) with a T of 42 °C;
- the waters that flow from the artesian aquifers at 560 m depth in the area of the mouth of the Tagliamento (Fourth Basin and Isola Picchi) with T up to 52 °C;
- the Cesarolo 1 well, drilled by AGIP for oil exploration (located in Veneto, 8 km west of Lignano), which met the Friulian Mesozoic platform at a depth of 727 m, where a temperature of 60 – 65 °C was measured.

More in detail, the geothermal system affecting the Veneto-Friuli coast is characterized by two main types of thermal aquifers:

- soft thermal aquifers, within the plio-quaternary and Miocene cover soils (maximum depth up to about 600 m), with temperatures up to over 40 °C (maximum 52 °C);
- brackish or deep salty aquifers, housed in the buried limestone structure (depth between 750 and 1000 m from the countryside), with a temperature of about 60 °C. This system is generally isolated from the overlying sweet aquifers by a septum of interposed impermeable formations (marl or flysch).

Low and high enthalpy sea thermal energy

Having considered the low wave energy potential as a disadvantage and the high sea thermal energy potential as an advantage of the northern Adriatic Sea, we decided to focus on the implementation of a sea thermal energy system.

It is important to keep in mind the most common classification parameter of geothermal resources which is based on the enthalpy of fluids, which transfer heat from deep hot rocks to the surface. Enthalpy is used to express the thermal content (thermal energy) of fluids and gives an approximate idea of their "value". Resources are divided into low, medium, and high enthalpy (or temperature) resources. Low temperature or “low enthalpy” geothermal energy is a renewable thermal energy resource that uses heat below 90 °C as its energy source. Geothermal heat pump systems exploit the thermal energy naturally available in the surface portion of the subsoil (within 200 m). Medium and high enthalpy resources are those that instead use heat as an energy source, respectively, at a temperature between 90 °C – 150 °C and above 150 °C. The high enthalpy geothermal fields are in the pre-Apennine belt (between Tuscany, Lazio, and Campania), in Sicily and Sardinia, as well as in the volcanic islands of the Tyrrhenian Sea. The territory of the Friuli-Venezia Giulia Region does not offer great possibilities for large plants at high temperatures, while it has an interesting installation capacity for those at low temperatures. By carrying out a more in-depth analysis of the resource in the area, we discovered that the resource is partially low enthalpy. However, this resource could guarantee substantial energy benefits through heat pumps. The areas with the highest temperature in the subsoil are those with numbers 1, 2 and 3, shown in the figure below.

Figure 79 - Geothermal potential areas in Friuli-Venezia Giulia

Geothermal and see thermal projects carried out in the region

Several geothermal and see thermal projects were carried out in the region. We summarize below the most significant ones.

Grado geothermal Project

In the Veneto-Friuli coast area, an explorative project was carried out. This "Grado geothermal Project" was the first initiative on the territory of the Friuli Venezia Giulia region, for the evaluation and rational exploitation of the geothermal waters contained in the limestone buried at about 600-700 m depth. The project consisted of two phases.

The Grado geothermal Project - Phase 1 was completed in 2008 by the Regione Friuli Venezia Giulia and it was mostly supported by European Union funding. This phase resulted in the feasibility of a geothermal district heating pilot plant on Grado Island, in the north-eastern Adriatic Sea (Italy). The reservoir characterization and the preliminary geothermal potential assessment rely on the geophysical prospect and an exploration, borehole drilled down to 1110 m. These investigations confirmed the existence of an untapped low-enthalpy geothermal reservoir within the Mesozoic carbonate platform buried beneath about 1 km of Paleogene and Neogene sediments, in correspondence with the structural highs along with the coastal areas.

In 2012, as part of the Grado geothermal Project - Phase 2, an integrated gravity and seismic geophysical prospecting, including multi-offset VSPs, was conducted in downtown Grado and its surrounding lagoon. The target was to extend the investigation of the geothermal reservoir and to provide adequate information on the faults/fracture systems interesting the buried external Dinaric thrust front. The results of the second phase allowed operators to locate the second well of the geothermal doublet, planned to feed the district heating system of public buildings on the island.

Pontebba Ice Rink Plants

The existing cooling system of the ice rink of Pontebba town (UD), located close to the Austrian border, was renovated in late summer 2012: an open-loop heat pump system using groundwater thermal energy was realized and functions both for the ice production and maintenance and for the heating and hot water needs of the ice stadium. Two ammonia heat pumps (350 kW each) were installed, supported by two production water wells (32 m deep) and one reinjection water well (30 m deep), drilled into the alluvial deposits of the Fella River. A total production rate of up to 200 t/h could be achieved from the shallow unconfined aquifer, with an average temperature of about 8.5 - 9.0 °C. Numerical modelling of groundwater flow supported the assessment of the production and reinjection rates, as well as the evaluation and the minimization of the impacts on the groundwater resource during the plant management in various hydraulic regimes. Over the first two years of operation, cost reductions of the order of 45% have been achieved.

Thermal energy from the sea for the city of Trieste: proposal for sustainable use

In 2014 the Trieste International Foundation and University of Trieste, in agreement with the Municipal Administration of Trieste, proposed to evaluate the construction of plants for the exploitation and distribution of hydrothermal energy derived from the Gulf of Trieste, on one or more buildings in the historic centre of the city, in the “Rive” area. This solution should have been achieved through a primary mini-district heating network, equipped with pipes positioned at adequate depth in the road section, without insulation, to allow each building to connect to the water supply and return seawater (in open circuit), or to connect to an intermediate technical water network (in closed circuit), which network requires a common exchanger with the sea resource. In the case of a solution with an open seawater circuit, the second section of the system consists of a heat exchanger connected to the open circuit ring and connected, on the other side, to a closed-loop ring, in which a fluid flows, which transfers heat to the heat pump serving the buildings connected to the network.

Portopiccolo seawater air conditioning system

The former limestone quarry of Sistiana, in the province of Trieste, was the subject of an important environmental restoration intervention. “Portopiccolo Sistiana” is a complex that includes 460 housing units, public and private beaches, green areas, bars and restaurants, hotels, 124 berths and a large spa. This is an entire village with energy efficiency class A. The centralized air conditioning system run with seawater and it is based on the water ring technology. Moreover, the plant is set up for the exploitation of groundwater, thanks to the contribution of the Timavo river. Seawater exchanges heat with the technical water circuit, which in turn brings the energy carrier to the 25 electric pumps located in the 18 sub-stations spread throughout the village, covering the heating, cooling and hot water needs of all utilities. After the construction of the infrastructures, the laying of the networks and the construction of the buildings, the small port was excavated and opened, allowing the start-up of the air conditioning system in April 2014.

Given the successful projects carried out in the Friuli Venezia Region, we decided to focus on the implementation of a sea thermal energy system.

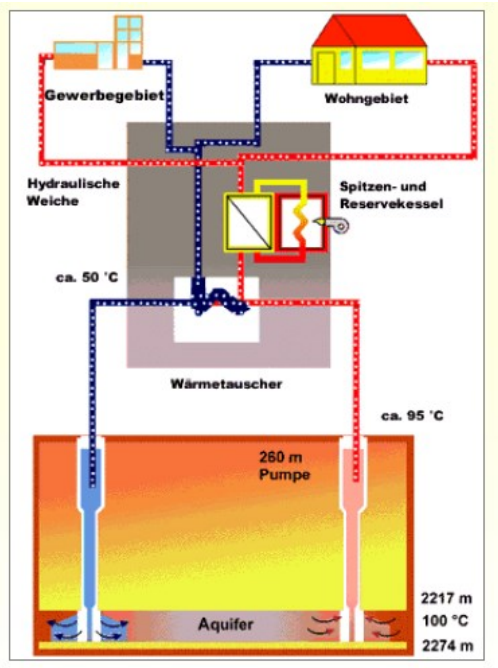
In the next section, we analyse the operating principle of the most successful technologies. We identified the following devices as the most suitable to be implemented in the area.

Process Description of the Geothermal District Heating Project

The first successful system in the region is a district heating plant (figure below) made by an extraction well and a re-injection well. The system guarantees to heat to public buildings. In the first phase of the project, the characterization and quantification of the available geothermal resource were carried out. The first phase ended with the following main activities: geological and geophysical investigations aimed at the location and design of the first exploratory well, the tender procedure for its construction, drilling, flow tests and well logs. The next phase included the second well drilling and surface systems building (i.e., heat exchangers, insulated pipes, and connections to the heating network).

The typology of this plant for the exploitation of terrestrial heat is known as “geothermal doublet” therefore based on a two-well system and on a surface heat exchanger that works in a binary cycle. In this way, the only net extraction from the subsoil is the heat exchange on the surface (heat mining) between the primary fluid from the well and the secondary fluid consisting of the freshwater of the city aqueduct. The project develops approximately between the Costa Azzurra beach, where you can find the exploration well and Piazza Carpaccio where the second well was built, both located within the perimeter of the mining concession obtained by the Municipality and extending over almost 6 km^2.

The fluid extracted from the first well is re-injected in depth through a second well after being circulated in a district heating network in turn connected to heat exchangers. The district heating network is connected to two wells of 1110 and 1200 m depth, located in the city and about a kilometre away. The derivation well supplies geothermal water at 45 – 47 °C which, circulating in the distribution network, transfers heat to the exchangers that heat the connected buildings. The water returning from the exchangers is collected and channelled to the reinjection well, into the same deep tank.



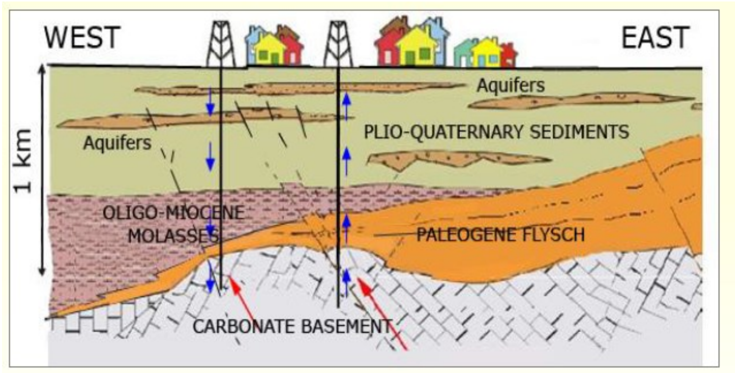


Figure 80 - Geothermal District Heating Pilot Project

Technical description of the air conditioning system

A second successful system in the region is an air conditioning system shown in the figure below. The seawater exchanges the heat with a technical water circuit which takes the energy to the electric heat pumps located in the sub-plants. The technical water circuit forms a ring that extends for about 2 km and, thanks to the operating temperatures always below 35 °C. The circuit was entirely made with polyethene pipes also used in the seawater network. The innovative part of the system is the power station powered by a medium voltage (20 kV) electrical substation. The power station is made by four heat exchangers of seawater and technical water (1 of which is designed for reserve only) each with a nominal power of 1.45 MW. These are plate exchangers, made of titanium and insulated to avoid condensation during the winter. The control system continuously detects its pressure drops and allows the operator to evaluate when maintenance is required (usually annual). The maintenance foresees disassembly and cleaning of the plates to remove the deposits. There is also the possibility of carrying out a chemical descaling of the exchangers without disassembling, through a special circuit and with the recovery of the fluid used for the operation.

Each exchanger is equipped upstream with a self-cleaning filter for the removal of algae: the control system automatically plans the flow inversions with a by-pass of the dirty water towards the exhaust manifold. The maximum heat output that can be extracted from seawater is around 4.5 MW (with 3 circuits out of 4, the other is a reserve). To date, the request has never gone beyond half of this value: not all users are still active.

The seawater treatment system injects ClO_2 according to its volumetric flow rate and its temperature. Before discharge, the presence of chlorine is monitored to comply with legislative constraints and, if necessary, dechlorinates are also added. The use of chlorinators and dechlorinates is significant in the summer when the number of algae increases and at the same time the demand for air conditioning increases and therefore a greater flow of water is needed.

The circulation of seawater is guaranteed by 4 centrifugal pumps powered by stainless steel inverters, with a nominal flow rate of 183 m^3/h each. The result is ΔT maximum seawater of about 4 – 5 °C. The water of the technical water distribution ring is instead handled in the central sea by 4 centrifugal pumps: 2 larges (274 m^3/h each), a medium and a small one, used according to the needs of the user. The result is ΔT technical water of about 3 °C.

In the plant, there are also two well-water-cooled fan coils for cooling the environment. The fan coils allow disposing of the thermal load to the outside, without having to use fans to guarantee a high air exchange.

To ensure the exchange of heat with the environment, the seawater intake was placed at a depth of 3.8 m, and the system could alternatively be supplied with water from two wells at a depth of 80 m or from the municipal aqueduct.

The analysis of the data recorded in over 2 years of constant monitoring of the plant shows that the system has performed well so far, showing excellent efficiencies and without approaching the constraints imposed by environmental protection. The seawater temperature reached a maximum summer peak of about 28 °C and a minimum of 9 °C, during a persistent Bora wind. The most critical conditions for the operation of the plant initially assumed for the summer were unexpectedly encountered in the winter. In the middle of winter, the operating temperatures of the technical water circuit are around 10 – 5 °C (flow/return), while the production of water for heating at about 40 °C must be guaranteed.

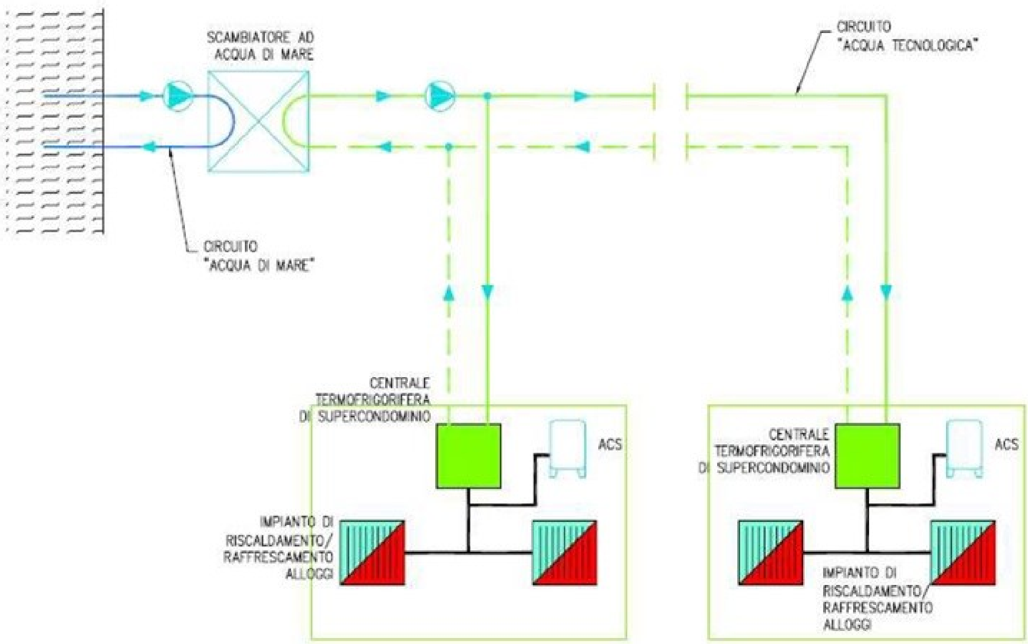


Figure 81 - Operating diagram of the seawater air conditioning system

Possible barriers to implementation

We conducted a first assessment of the possibility of exploitation of the geothermal resource at a regional level. The result is that the territory of the Friuli Venezia Giulia region does not offer great possibilities for large high-temperature systems, while it has interesting installation capacity for low-temperature ones.

Physical requirements for installation

As regards physical requirements, the installation of a geothermal plant needs the availability of enough soil, to the type of plant you want to build, for drilling or for laying. For instance, in the case of installation of horizontal probes, the necessary external surface must correspond to a percentage between 100% and

150% of the surface to be heated. Moreover, to evaluate the convenience of the system, it is important to know the characteristics of the subsoil that you intend to use as a heat source, both to check the technical feasibility and any hydrogeological constraints and to verify, based on the type of soil, the performance of the subsoil. The thermal conductivity of the soil (in other words its ability to transmit heat) varies according to the type of subsoil.

Authorizations and regulations for installation

A provincial authorization should be asked to the region, in the case of small geothermal uses that exchange heat directly with the subsoil or with the aquifers without carrying out the withdrawal of fluids. This authorization is provided through the Water Protection Plan which aims to protect the groundwater.

As regards the installation of vertical geothermal probes, the authorizations are regulated by local authorities, generally by the Regions and in some cases directly by the Provinces or Municipalities. While in the case of a system with horizontal probes, the maximum excavation depth does not normally exceed two meters and therefore no authorization is required.

As for geothermal installations that use groundwater as a thermal source, the legislation that regulates the sector in Italy takes as reference the national law on water and protection of the subsoil (single environmental text Legislative Decree 152/2006). The province of Trieste together with ARPA (Regional Agency for Environmental Protection), has established the respect of the national constraints and the obligation to install a monitoring system able to guarantee constantly:

- a threshold on the maximum discharge temperature of 35 °C;
- an increase in sea temperature 1 km from the discharge below 33 °C;
- a limit to the presence of residual chlorine at the discharge of fewer than 0.2 parts mg/l.

During the drilling and recombination operations, all the safety measures must be taken to avoid:

- to penetrate waterproof layers by connecting several aquifers;
- the contamination and pollution of the subsoil and/or groundwater caused by the use of additives, from leaks or other operating irregularities of the plant;

- negative consequences for soil and subsoil due to oil, fuel, additives, or other products of the drilling machines (the soil under the drilling machines must be protected by waterproof sheets and collection tanks).

The holes for the vertical geothermal probes must respect the legal distances from the property borders and a minimum distance of 4 meters in any case. The drilling cannot be carried out near existing water utilities and 100 meters from public drinking water supply wells in any case. During the drilling and before commissioning the plant, a report must be drawn up with:

- punctual data relating to drilling with an indication of the stratigraphy of the subsoil, inflows of groundwater, losses of drilling water, technical data on the type of drilling and recombination, materials and additives used, situations and events;
- technical data and results of the tightness tests of the geothermal probe.

Economic and financial impacts

Portopiccolo Seawater air conditioning system

Concerning the Portopiccolo Seawater air conditioning system, the technology taken as a reference is characterized by the fact that it can be present anywhere in the soil, it also has a low energy and environmental impact. The cost of the system (mechanical, electrical, and sanitary installations) is approximately about 25 million euros. The air conditioning system is about 2.5-3 million euros, of which 1.6 million euros only for the sea power plant and technical water ring. It is a system that has a high initial investment, linked to the total area to be supplied. The theoretical cost estimation would result in a cost for the probes starting from 8/10 thousand euros, the average cost of the company carrying out the survey would be approximately 900 euros while the cost for the survey would be around 40-80 euros per meter, depending on the type of soil. Taking as reference an apartment of 80 square meters, the hypothetical investment would be equal to 15-20 thousand euros, the more the area, the more the cost.

Grado geothermal Project

In the geothermal project of Grado completed in 2014, a network was created to connect six public buildings such as a gym, hotel, auditorium, library, middle school, former school. The total cost is approximately about 5 million euros: 2.5 million euros in phase one of assessment of the geothermal resource and further 2.5 million euros in phase two of design and realizes the geothermal doublet. In detail, the costs of the two geophysical surveys, logs, coring, production tests were 0.8 million euros, the design and field supervision amounted to around 0.2 million euros, one production and one re-injection wells of approximately 2 million euros and the district heating network, circulation pumps and heat exchangers for a cost of 2 million euros.

Conclusions

From the analysis carried out, it emerges that geothermal and hydrothermal energy is currently an underdeveloped sector, it does not take off. To promote a plan for the conservation and development of the use of geothermal energy, the Region has financed various studies and research reported below:

- "Preliminary study of deep aquifers" which allowed to reconstruct the geometry and characterization of the aquifers deep in the Friuli plain;
- "Creation of the geological-technical map of the regional geothermal resource and definition of the guidelines for its use";
- "Geothermal Project" including the "Construction of an exploratory well and the quantification and parameterization of the geothermal resource in the Municipality of Grado".

As regards geothermal installations that exploit groundwater as a thermal source, the legislation that regulates the sector in Italy refers to the national law on water and protection of the subsoil, therefore not providing a specific regional regulation.

Also, from a first analysis of the costs of these systems, it can be deduced that these are plants with a high initial investment, however, their useful life can extend to several generations. Risk and capital expenditure are concentrated in the initial phases of a project, only when the initial drilling has been completed the quality of geothermal resources can be demonstrated.

3.6 Community of Mediterranean Universities

Introduction

Starting from an analysis of the marine energy potentials of the Apulia Region, the present work has attempted to create a reference framework on existing technologies, and then to focus on four technologies, including three onshore and one offshore, capable of producing electricity thanks to the exploitation of wave motion.

Specifically, the energy potentials of wave height, wave power and sea thermal at 5 and 300 meters of depth, as well as the general bathymetric condition of the entire region, have been analysed.

The pilot area is Mola di Bari, and the four selected technologies are Eco Wave Power, Obrec, Rewec and Iswec. They are all technologies exploiting wave motion, with the difference that, while the first three (Eco Wave Power, Obrec and Rewec) are installed onshore, the Iswec is moored offshore.

The data on energy potentials processed in this document is based on the MAESTRALE webGIS available at http://maestrale-webgis.unisi.it/

Bathymetry in the Apulia Region

The bathymetry of the Apulia Region, unlike other Italian regions facing the Adriatic Sea, has more important depths offshore, in some cases even exceeding 2,000 meters at a distance of about 50 km from the coast – whereas, at the same distance off other Italian regions, they do not exceed 200 meters. On the other hand, within the first 20 km from the coast, the bathymetry is very similar to that of the whole Adriatic, as it rarely exceeds 100 meters.

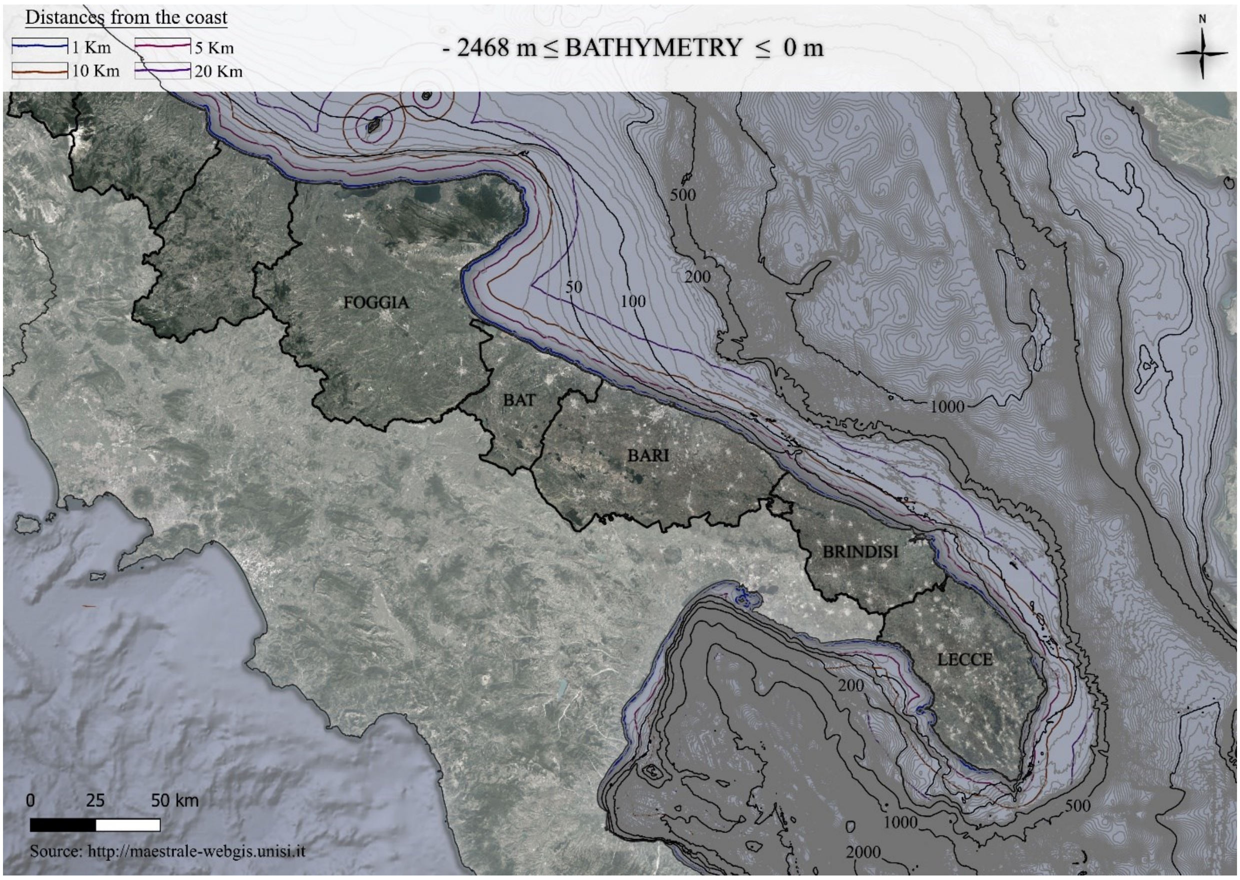


Figure 82 - Bathymetry in the Apulia coast

Wave energy potential in the Apulia Region

The marine energy potential of the waves in the Apulia Region is low compared to that of the northern European seas. If, on the other hand, it is compared to that of the other Italian regions facing the Adriatic Sea, it is certainly among the highest. As shown by the following two figures, it is possible to find in Apulia a wave height between 0.082 meters and 0.946 meters. The power of the waves, on the other hand, is between 0.010 kW/m and 1.852 kW/m. These data refer to annual rates.

These data certainly exclude many technologies, already tested in the seas of northern Europe, and needing much higher potentials.

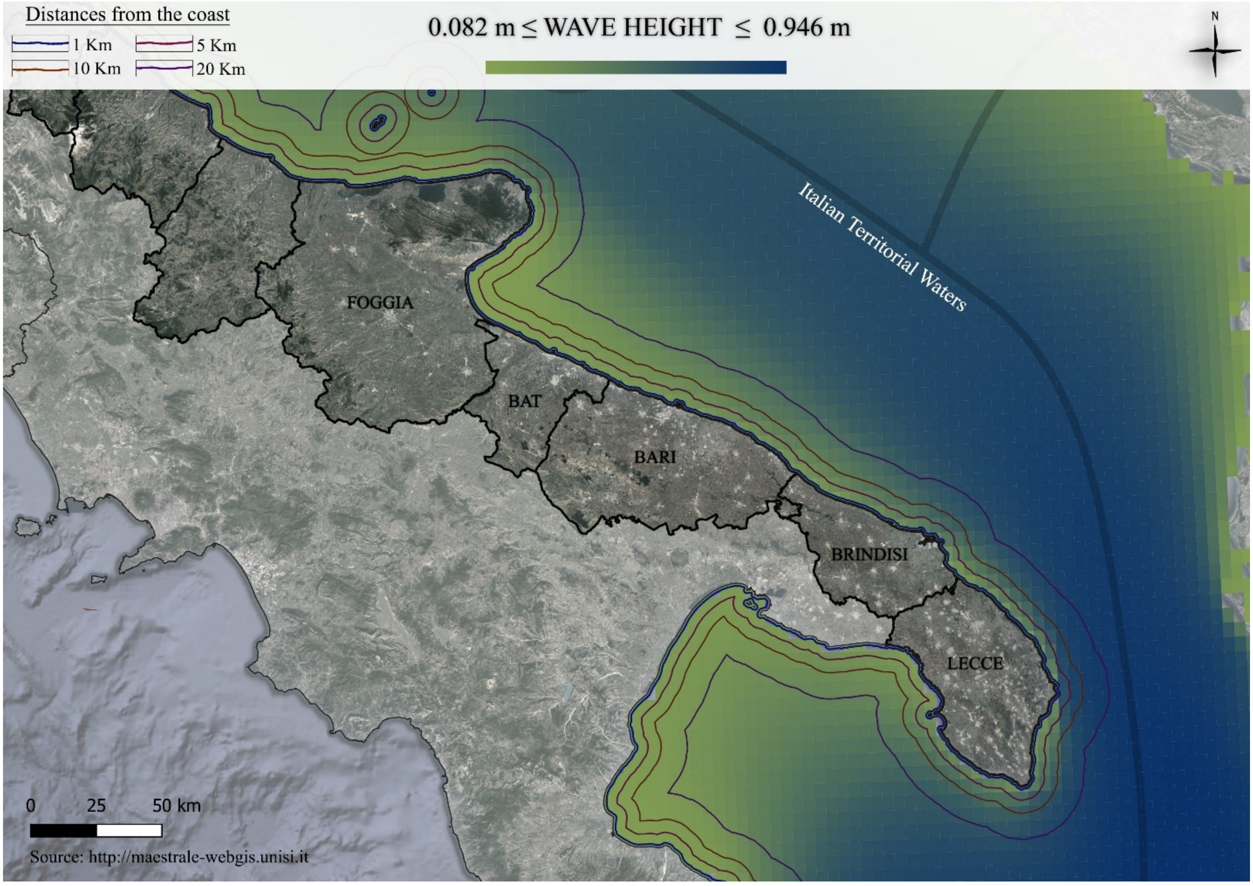


Figure 83 - Wave heights off the Apulian coast

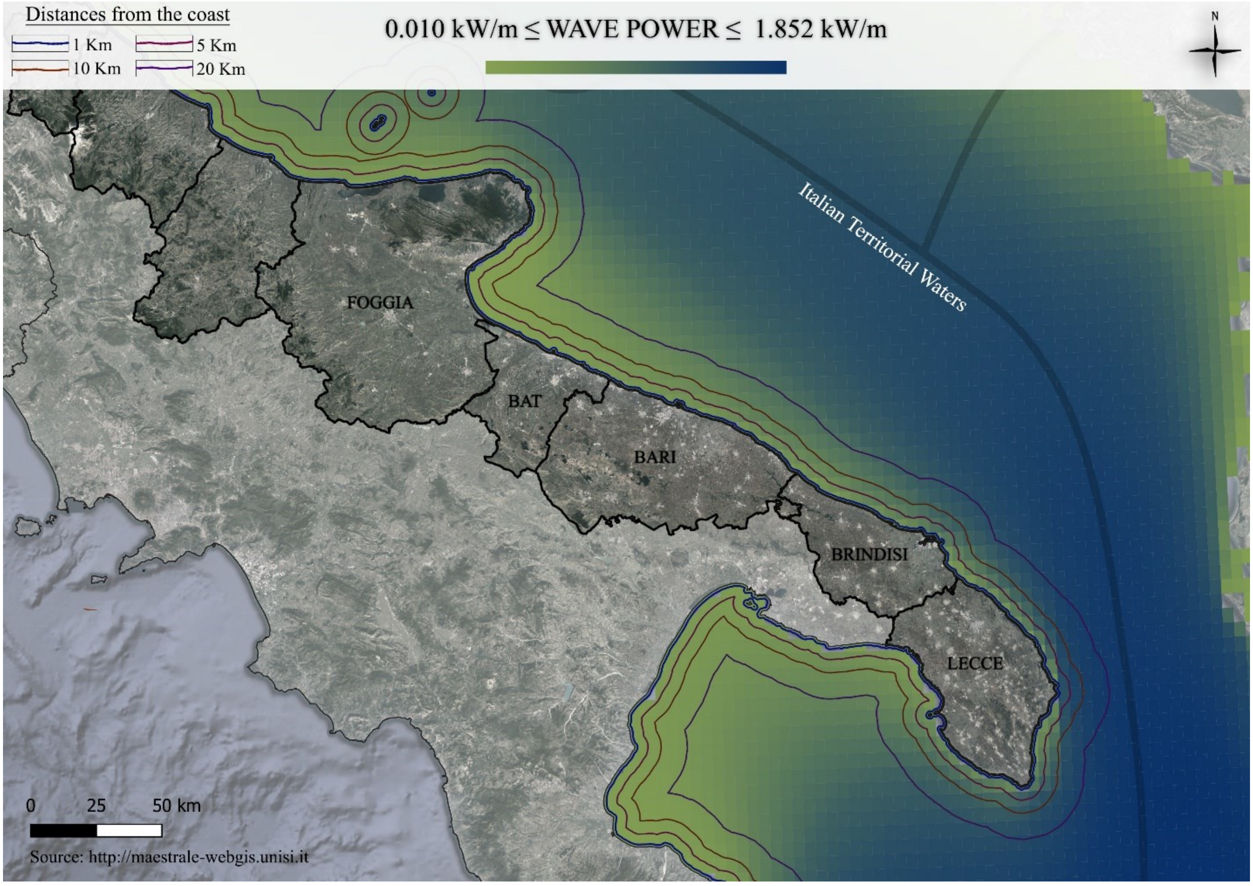


Figure 84 - Wave power off the Apulian coast

Sea temperatures in the Apulia Region

In addition to wave potentials, sea temperatures at two different depths were analysed, to have a general picture of the regional situation.

The analyses concerned temperatures at depths of 5 and 300 metres. In the first case (5 m), the interannual averages vary between 17.826 °C and 19.975 °C. At a depth of 300 metres, however, temperatures range from 13.876 °C to 14.710 °C.

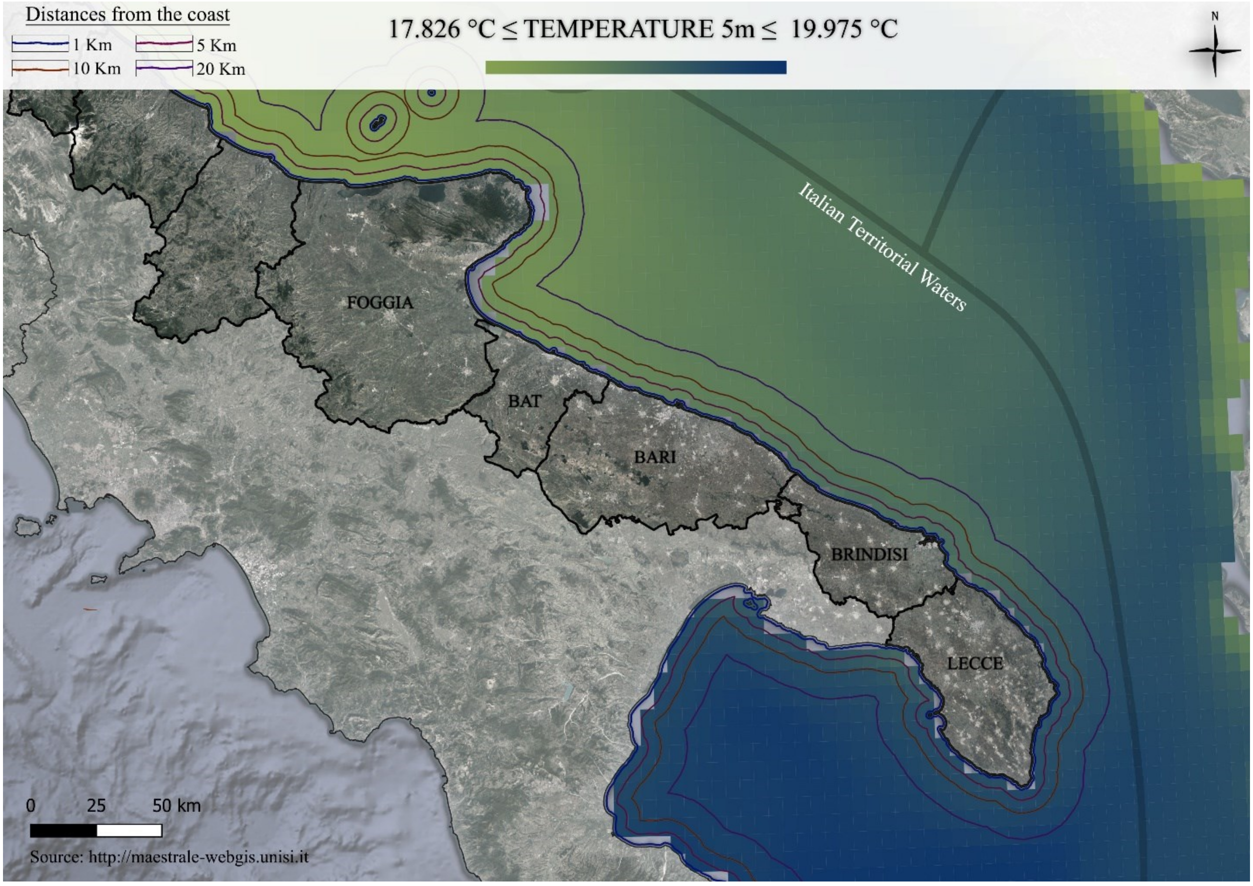


Figure 85 - Sea temperatures (5 m depth) of the Apulian coast

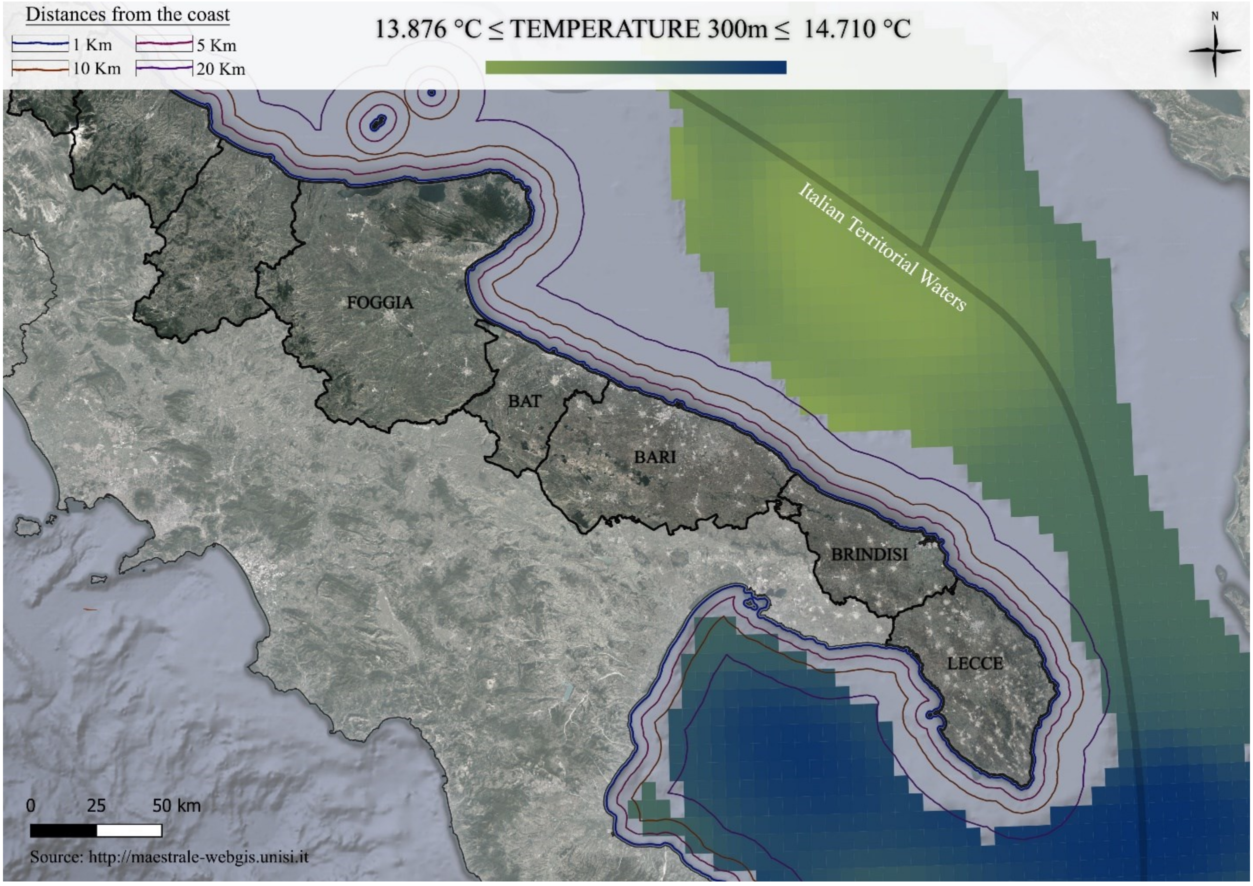


Figure 86 - Sea temperatures (300 m depth) of the Apulian coast

Analysis and selection of wave technologies for the pilot area of Mola di Bari

Following the analysis and selection of the first range of technologies, this second selection phase focused on selecting only those technologies being at a more advanced technology readiness level, to understand the real potential of the application.

Furthermore, the attention has shifted to the technologies developed in Italy, to overcome application problems, considering that most of the technologies being developed are tested in the northern European sea, where climatic and physical conditions of the seas are very different, resulting in a difficult application in our seas, even considering the possibility of a downscaling.

The technologies selected for the pilot project of Mola di Bari

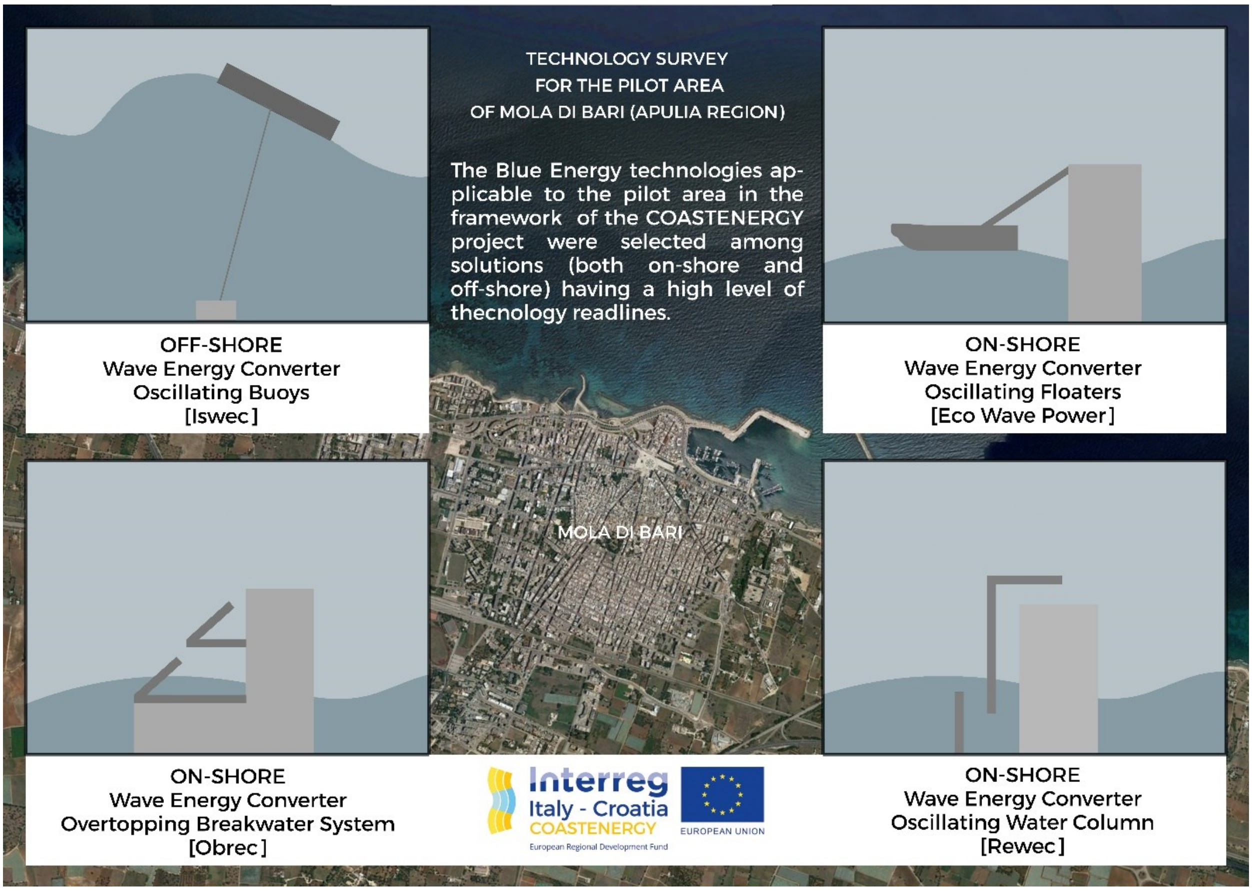


Figure 87 - Technologies selected for the pilot area of Mola di Bari

As anticipated, following an initial analysis of the technologies, the selection of the four proposals for the pilot project concerned first criteria for applicability to the Mediterranean, from bathymetry to energy potentials, but above all, the technology readiness level. This last criterion was indispensable for understanding the real application in the pilot area. Having selected only technologies tested in Italy and with a high technological advancement will allow extracting, in the next phases, concrete data on energy production and, therefore, on the real sustainability of their application in the pilot area.

Some physical characteristics necessary for the application of every single technology, and the related productivity data, are described below.

- REWEC (wave energy converters – oscillating water columns):
    - wave height (minimum) = 0.5 m;
    - -2.5 ≤ water depth ≤ -15 m;
    - 250 MWh/yr ≤ estimated electricity production (16-24 turbines) ≤ 500 MWh/yr;
- OBREC (wave energy converters – overtopping breakwater):
    - wave energy power (minimum) = 25kW/m;
    - -2 m ≤ water depth ≤ -10 m;
    - estimated electricity production (20 x 3 kW turbines): 200-250 MWh/yr;
- Eco Wave Power (wave energy converters – onshore floaters):
    - wave energy power (minimum) = 1 kW/m;
    - wave height (minimum) = 0.5 m;
    - 250 MWh/yr ≤ estimated electricity production (25-33 turbines) ≤ 450 MWh/yr;
- ISWEC (wave energy converters – oscillating buoy):
    - wave height (minimum) = 5 m;
    - -25 m ≤ water depth ≤ -50 m;
    - 12 MWh/yr ≤ estimated electricity production (1 device) ≤ 250 MWh/yr.

The pilot area

Mola di Bari and its port

Mola di Bari has 25,173 inhabitants and is part of the metropolitan city of Bari. Its economy has always been largely based on fishing, for this reason, it has a strong connection to the sea. Its fishing port is among the most important in the region: it hosts around 350 pleasure boats and 115 fishing boats. It is one of the most important maritime realities of the metropolitan city of Bari and one of the first in the entire Adriatic. The port is sheltered to the north by a three-armed pier, and to the east by the new two-arm pier, approximately 700 m long; the east arm encloses the old port basin. Inside the harbour basin, there are some floating piers.

Figure 88 - A satellite photo of Mola di Bari

Mola di Bari wave project

Thanks to the total funding of 2 million euro obtained by the municipal administration of Mola, as part of a specific project of the Interreg Italy-Greece programme, the entire port will soon be affected by various refurbishment works that will change the entire aspect of the seafront in the coming years. For these reasons, Mola di Bari is certainly an ideal candidate for the integration of Blue Energy systems. Indeed, as anticipated, three of the four selected technologies would be installed onshore, where they could profit from the plans for refurbishing the port.

Specifically, the proposal for the integration of blue energy systems requires the installation of some OBREC, REWEC, and Eco Wave Power systems on the docks that are more exposed to sea currents. This choice is given by the fact that these technologies (OBREC in particular) have been studied with a dual function: in addition to generating electricity, they also protect the port just as a breakwater. The proposal to install the ISWEC systems meets the need to increase energy productivity, thanks to the integration of multiple technologies, to make Mola a truly "green" port.

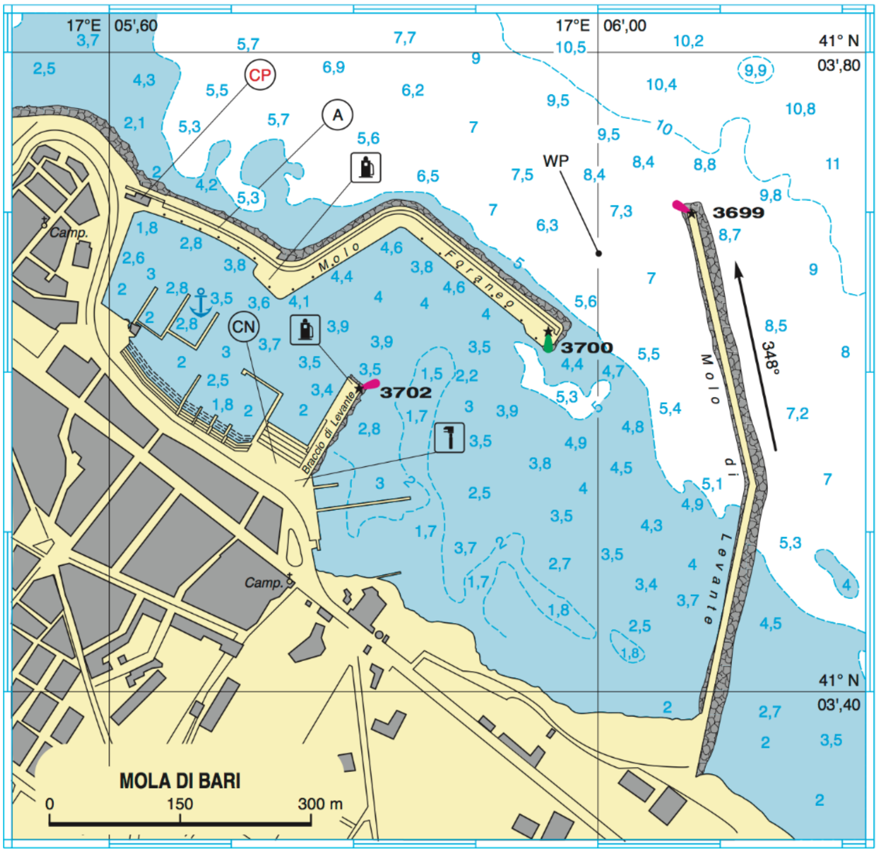


Figure 89 - Port of Mola di Bari

3.7 Chamber of Commerce Chieti-Pescara

Introduction

The following report provides general information on marine energy potentials on the coast of Pescara and more specific information concerning three possible pilot areas for the implementation of Blue Energy technologies. In particular, the case studies include three ports in Pescara, Ortona and Vasto.

Pilots have been selected based on meetings with experts of the Chamber of Commerce (main conductor of the Pescara Marina) with knowledge on the current state and strategies regarding the development of ports in the regional coast.

The three pilots must be further discussed with local stakeholders and two out of three will be finally selected as pilot studies for the COASTENERGY project. The selection of pilots will consider potentials for the installations of on-shore marine energy technologies, including, as a primary choice, wave energy converters embedded in piers and, possibly, seawater-based heat pump systems.

Most of the information reported concerns the current state of the three ports and their planned development in compliance with the Structural Plan of each port that has been already approved by the Regional and the Maritime Authorities.

Marine energy potentials at a regional level

Energy potentials concerning wave energy and seawater heat are presented in the following maps, together with the bathymetry, to give a general overview of the potentials in the Abruzzo Region. Data are based on the MAESTRALE webGIS available at http://maestrale-webgis.unisi.it/

The bathymetry does not exceed 50 m within 10 km from the shore. It is less than 100 m within 20 km and rarely achieves the limit of over 200 m.

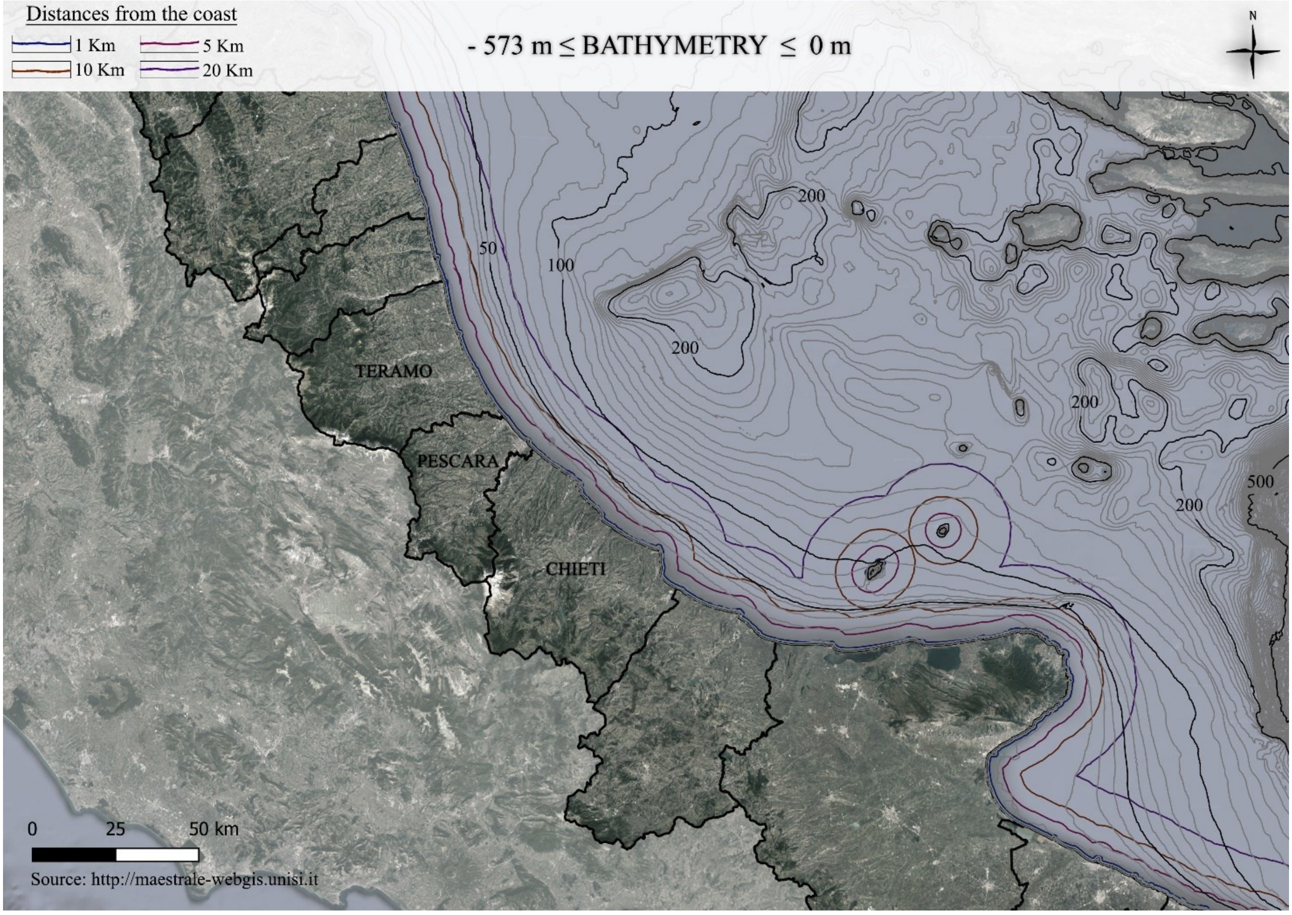


Figure 90 - Bathymetry in the Abruzzo coast

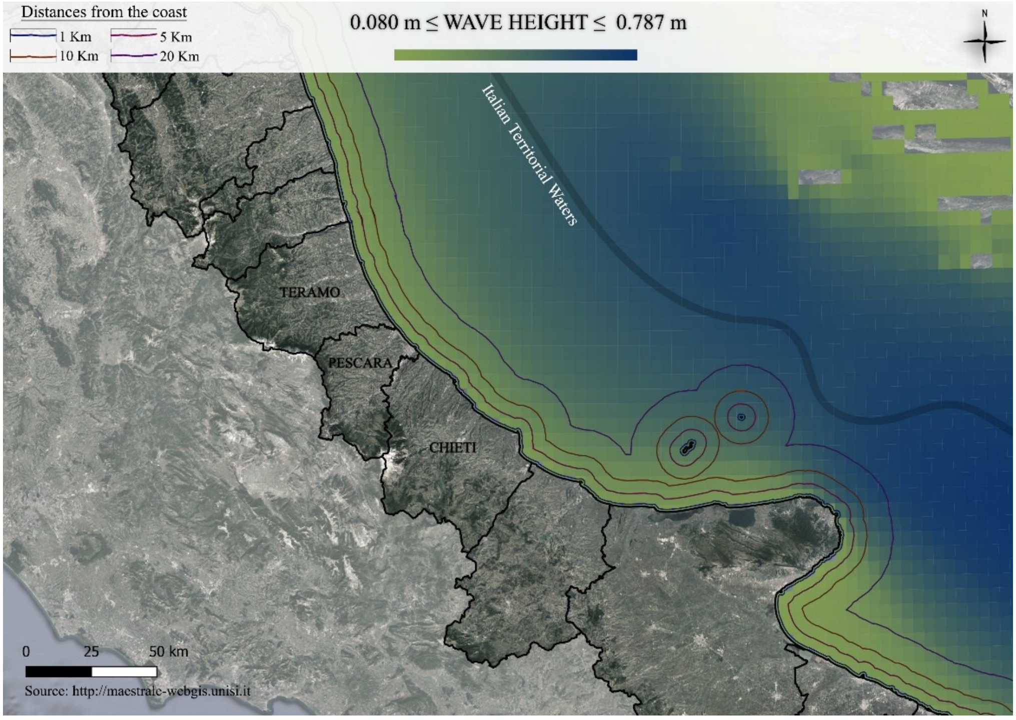


Figure 91 - Wave height in the Abruzzo coast

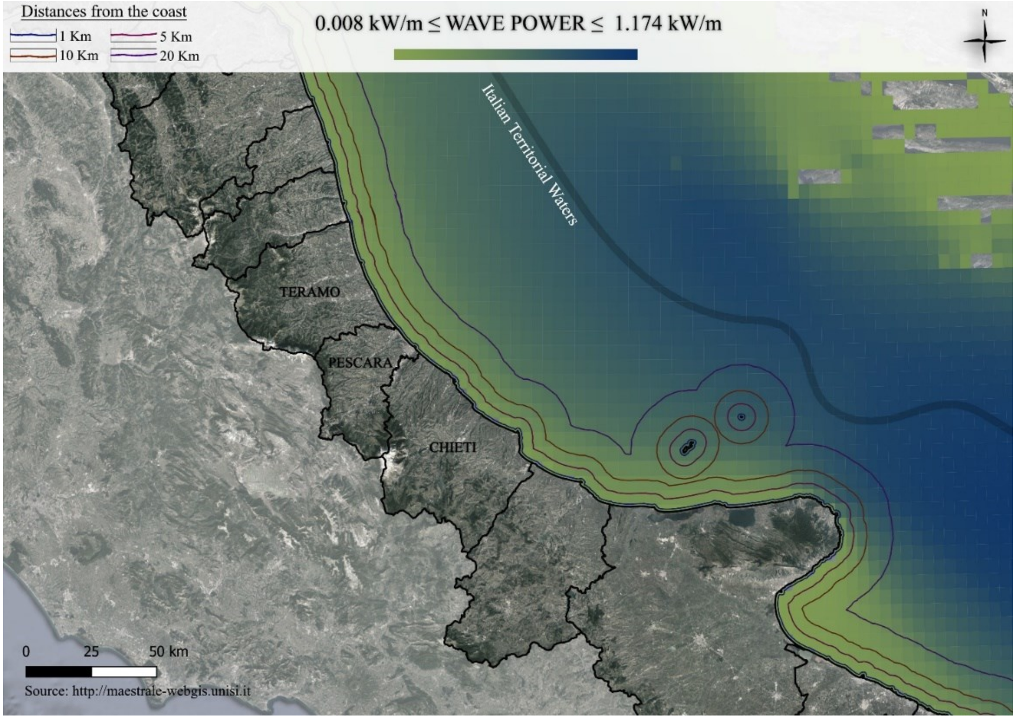


Figure 92 - Wave power in the Abruzzo coast

Wave height ranges from 0.080 m e 0.787 m, also due to the low bathymetry. Wave power ranges from 0.008 kW/m and 1.174 kW/m as average. Anyhow, potentials for exploitation exist due to the frequency and predictability of wave motion. The temperature gradient between seawater (with lower oscillations) and the external air allows for possible exploitation through heat exchangers and seawater-based heat pump systems. In general, the average temperature at 5 m depth ranges from 17.1°C and 19.3°C; and from 13.8°C and 14.0°C at 300 m depth.

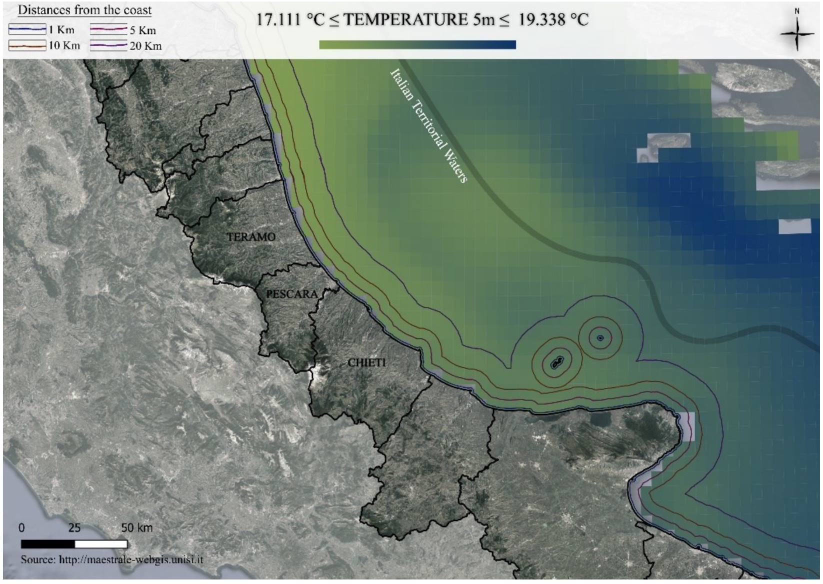


Figure 93 - Seawater temperature in the Abruzzo Region. Depth: 5 m

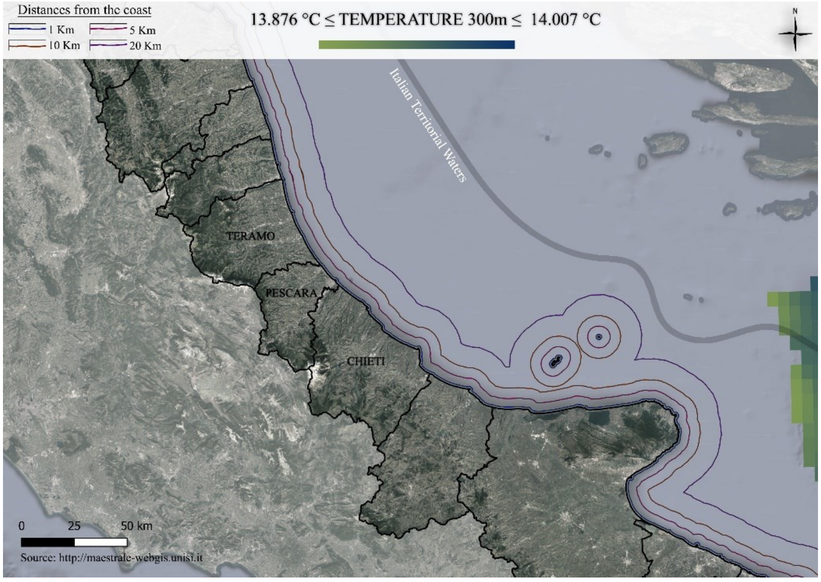


Figure 94 - Seawater temperature in the Abruzzo Region. Depth: 300 m

Pilot #1 – Pescara Marina

Description

The Marina of Pescara is a tourist port with a few non-relevant commercial functions. The port has been fully renewed in the ’50s and the current configuration was built in the ’80s. More recent interventions (ended in 2004) aimed at stretching the Pescara river mouth to protect the coast from its polluted outflow. Nowadays, the deposition of sediments from the river risks limiting access to the port; moreover, as in many Mediterranean ports, the physical and visual separation of the port from the city due to boundaries and barriers is a limiting factor for the potential use of multiple services by citizens. The Chamber of Commerce of Pescara-Chieti is the authority currently in charge of the management of the Marina.

Figure 95 - Pescara Marina: current state

Structural plan of Pescara Marina

A Structural Plan for Pescara Marina has been recently approved including a set of interventions that have to be implemented:

- fixing of problems concerning the deposition of sediments from the Pescara river that often compromises accessibility from the sea;
- enhancement of the touristic function and related services in the marina;
- extension of the port for the mooring of cruise boats;
- the building of an additional basin for fishing boats on the northern side;
- renovation of the riversides including traditional structures for fishing (*trabucchi*) and pedestrian areas;
- extension of operational areas in the marina (especially for cruise boats);
- increased accessibility to services by the landside and building of a new maritime station (improved connection with the city).

The project of the new basin for fishing boats has been recently abandoned due to consultations with owners that finally expressed their willingness to use the river basin for mooring considering that lower levels of salinity allow for less maintenance and a longer lifetime of boat crafts and helix.

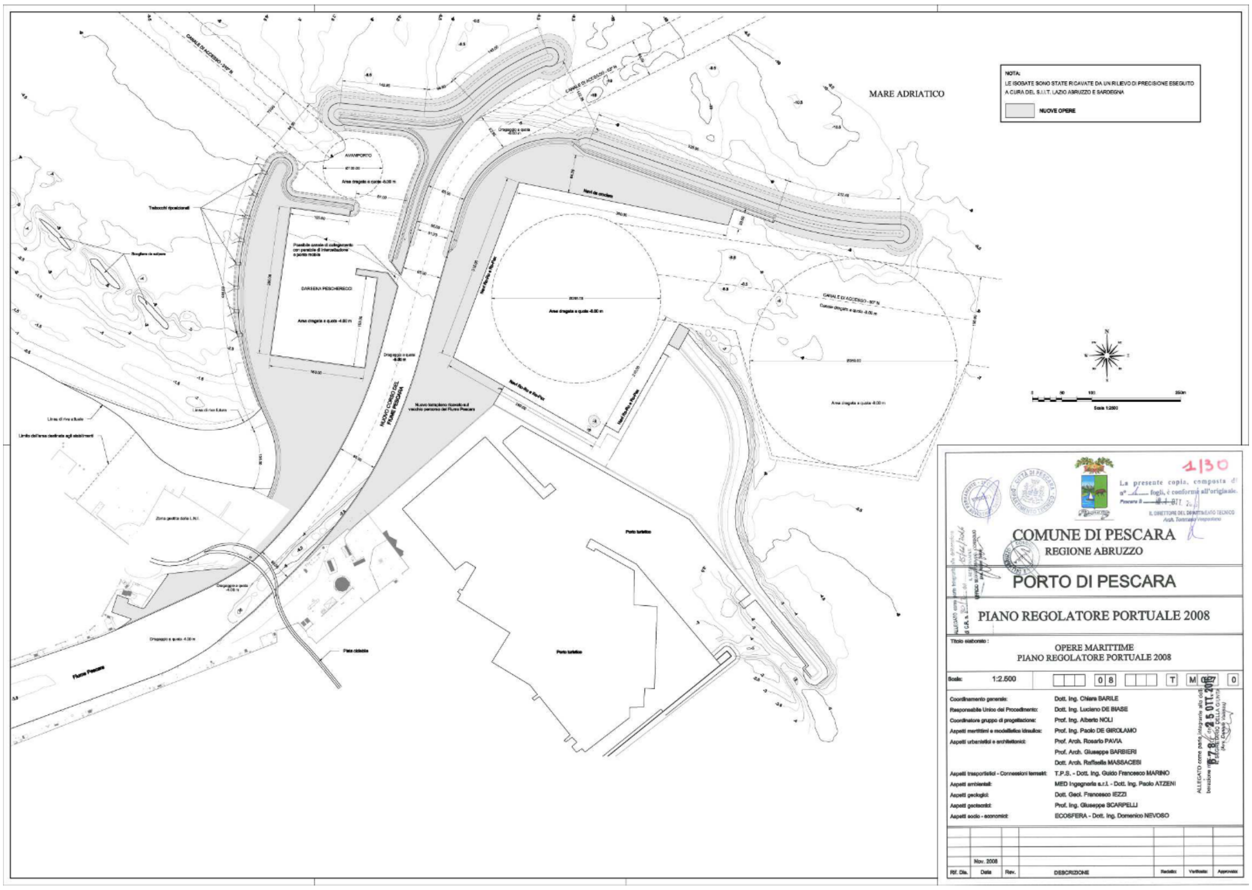


Figure 96 - Approved Structural Plan of the Pescara Marina

Climate and wave energy potentials

A detailed analysis of the marine energy potentials has been conducted by prof. ing. Paolo De Girolamo and included in the documentary material of the Structural Plan. Analysed parameters include wave energy, tidal changes, winds, and marine currents. Wave energy has been detected based on data collected by the buoy located in Ortona (18 years' time series), as part of the National Wave Network managed by APAT.

Data elaboration highlighted that the origin of waves near the shore mainly ranges from 340° N and 110° N with a wave high from 0.5 m to 2.0 m.

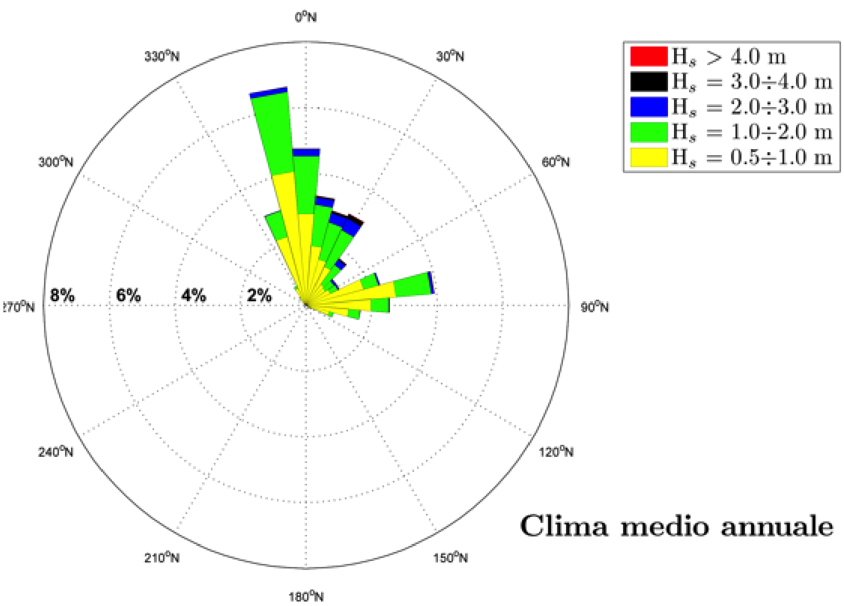


Figure 97 - Nearshore waves – Pescara P1 (Source: Port Structural Plan)

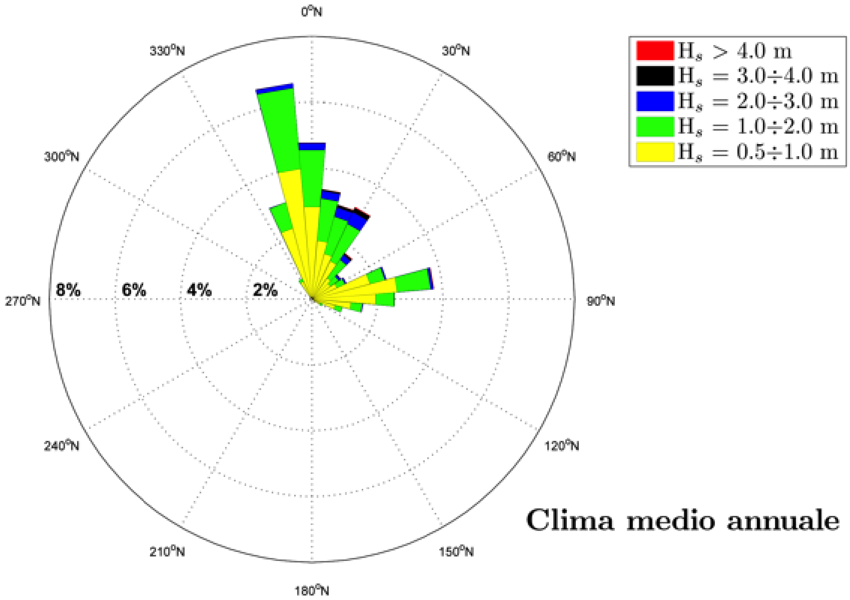


Figure 98 - Nearshore waves – Pescara P2 (Source: Port Structural Plan)

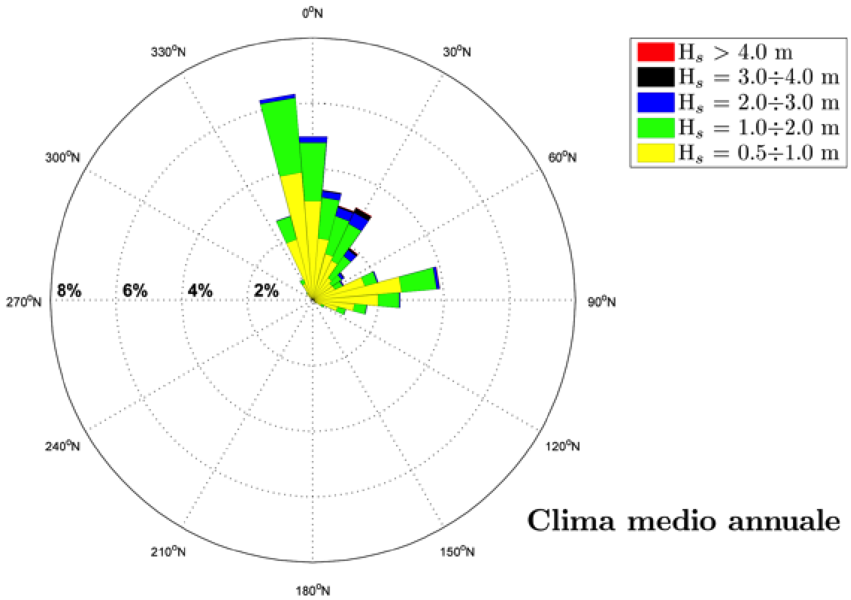


Figure 99 - Nearshore waves – Pescara P3 (Source: Port Structural Plan)

CLIMA ANNUALE

	Classi di altezza d'onda significativa H_{m0} (m)															
Dir (°N)	0 0.25	0.25 0.50	0.50 1.00	1.00 1.50	1.50 2.00	2.00 2.50	2.50 3.00	3.00 3.50	3.50 4.00	4.00 4.50	4.50 5.00	5.00 5.50	5.50 6.00	6.00 6.50	> 6.50	Tot.
10	667	768	749	371	153	63	35	13	3	2	1					*2 825*
20	508	546	595	370	128	86	44	19	14	5						*2 315*
30	448	478	546	345	168	108	53	45	16	10	1					*2 218*
40	403	424	315	191	107	57	19	12	11	1						*1 540*
50	437	515	293	103	28	22	4	3	2							*1 407*
60	441	577	349	91	28	8	7	3		1						*1 505*
70	599	997	803	186	45	16	2									*2 648*
80	680	1 433	1 170	355	66	23	13	3								*3 743*
90	755	1 235	840	207	23	2	4									*3 066*
100	672	1 200	546	114	13	4										*2 549*
110	603	690	305	49												*1 647*
120	520	205	63	5												*793*
130	508	55	12													*575*
140																*0*
150																*0*
160																*0*
170																*0*
180																*0*
190																*0*
200																*0*
210																*0*
220																*0*
230																*0*
240																*0*
250																*0*
260																*0*
270																*0*
280																*0*
290																*0*
300																*0*
310	48															*48*
320	932	458	155	4												*1 549*
330	410	607	266	49	3											*1 335*
340	417	1 003	968	336	59	11										*2 794*
350	550	1 300	1 671	763	258	61	11	3								*4 617*
360	651	1 212	1 178	531	216	62	21	5	2	1						*3 879*
Tot.	***10 249***	***13 703***	***10 824***	***4 070***	***1 295***	***523***	***213***	***106***	***48***	***20***	***2***	***0***	***0***	***0***	***0***	***41 053***

CLIMA ANNUALE

	Classi di altezza d'onda significativa H_{m0} (m)															
Dir (°N)	0 0.25	0.25 0.50	0.50 1.00	1.00 1.50	1.50 2.00	2.00 2.50	2.50 3.00	3.00 3.50	3.50 4.00	4.00 4.50	4.50 5.00	5.00 5.50	5.50 6.00	6.00 6.50	> 6.50	Tot.
10	1.27	1.46	**1.43**	**0.71**	**0.29**	0.12	0.07	0.02	0.01							*5.38*
20	0.97	1.04	**1.13**	**0.70**	0.24	0.16	0.08	0.04	0.03	0.01						*4.41*
30	0.85	0.91	**1.04**	**0.66**	**0.32**	0.21	0.10	0.09	0.03	0.02						*4.22*
40	0.77	0.81	**0.60**	**0.36**	0.20	0.11	0.04	0.02	0.02							*2.93*
50	0.83	0.98	**0.56**	0.20	0.05	0.04	0.01	0.01								*2.68*
60	0.84	1.10	**0.66**	0.17	0.05	0.02	0.01	0.01								*2.87*
70	1.14	1.90	**1.53**	**0.35**	0.09	0.03										*5.04*
80	1.29	2.73	**2.23**	**0.68**	0.13	0.04	0.02	0.01								*7.13*
90	1.44	2.35	**1.60**	**0.39**	0.04		0.01									*5.84*
100	1.28	2.28	**1.04**	0.22	0.02	0.01										*4.85*
110	1.15	1.31	**0.58**	0.09												*3.14*
120	0.99	0.39	0.12	0.01												*1.51*
130	0.97	0.10	0.02													*1.09*
140																*0.00*
150																*0.00*
160																*0.00*
170																*0.00*
180																*0.00*
190																*0.00*
200																*0.00*
210																*0.00*
220																*0.00*
230																*0.00*
240																*0.00*
250																*0.00*
260																*0.00*
270																*0.00*
280																*0.00*
290																*0.00*
300																*0.00*
310	0.09															*0.09*
320	1.77	0.87	**0.30**	0.01												*2.95*
330	0.78	1.16	**0.51**	0.09	0.01											*2.54*
340	0.79	1.91	**1.84**	**0.64**	0.11	0.02										*5.32*
350	1.05	2.47	**3.18**	**1.45**	**0.49**	0.12	0.02	0.01								*8.79*
360	1.24	2.31	**2.24**	**1.01**	**0.41**	0.12	0.04	0.01								*7.38*
Tot.	***19.51***	***26.09***	***20.61***	***7.75***	***2.47***	***1.00***	***0.41***	***0.20***	***0.09***	***0.04***	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***78.16***
Tot. Cumulato		***45.60***	***66.20***	***73.95***	***76.42***	***77.41***	***77.82***	***78.02***	***78.11***	***78.15***	***78.15***	***78.16***	***78.16***	***78.16***	***78.16***	

Figure 100 - Nearshore wave height (m): yearly time series – Pescara P1

CLIMA ANNUALE

Dir (°N)	Classi di altezza d'onda significativa H_{m0} (m)															
	0 0.25	0.25 0.50	0.50 1.00	1.00 1.50	1.50 2.00	2.00 2.50	2.50 3.00	3.00 3.50	3.50 4.00	4.00 4.50	4.50 5.00	5.00 5.50	5.50 6.00	6.00 6.50	> 6.50	Tot.
10	651	763	760	384	158	66	37	13	3	2	1					*2 838*
20	511	551	603	364	129	88	43	20	14	5						*2 328*
30	450	477	533	345	174	105	57	45	17	9	1					*2 213*
40	425	445	341	188	102	55	13	12	10	1						*1 592*
50	426	510	274	98	24	21	5	3	2							*1 363*
60	447	579	360	90	28	10	6	2		1						*1 523*
70	603	1 028	803	187	45	14	2									*2 682*
80	687	1 408	1 130	355	67	23	12	3								*3 685*
90	759	1 233	795	196	24	2	3									*3 012*
100	661	1 154	518	136	20	4	2									*2 495*
110	619	686	303	71	9											*1 688*
120	521	225	123	22	1											*892*
130	399	59	28													*486*
140																*0*
150																*0*
160																*0*
170																*0*
180																*0*
190																*0*
200																*0*
210																*0*
220																*0*
230																*0*
240																*0*
250																*0*
260																*0*
270																*0*
280																*0*
290																*0*
300																*0*
310	51															*51*
320	985	410	87	4												*1 486*
330	420	636	299	56	3											*1 414*
340	430	1 032	964	337	63	11										*2 837*
350	562	1 301	1 688	773	258	57	11	1								*4 651*
360	645	1 193	1 160	519	209	60	22	6	1	2						*3 817*
Tot.	*10 252*	*13 690*	*10 769*	*4 125*	*1 314*	*516*	*213*	*105*	*47*	*20*	*2*	*0*	*0*	*0*	*0*	*41 053*

CLIMA ANNUALE

Dir (°N)	Classi di altezza d'onda significativa H_{m0} (m)															
	0 0.25	0.25 0.50	0.50 1.00	1.00 1.50	1.50 2.00	2.00 2.50	2.50 3.00	3.00 3.50	3.50 4.00	4.00 4.50	4.50 5.00	5.00 5.50	5.50 6.00	6.00 6.50	> 6.50	Tot.
10	1.24	1.45	**1.45**	**0.73**	**0.30**	0.13	0.07	0.02	0.01							*5.40*
20	0.97	1.05	**1.15**	**0.69**	0.25	0.17	0.08	0.04	0.03	0.01						*4.43*
30	0.86	0.91	**1.01**	**0.66**	**0.33**	0.20	0.11	0.09	0.03	0.02						*4.21*
40	0.81	0.85	**0.65**	**0.36**	0.19	0.10	0.02	0.02	0.02							*3.03*
50	0.81	0.97	**0.52**	0.19	0.05	0.04	0.01	0.01								*2.59*
60	0.85	1.10	**0.69**	0.17	0.05	0.02	0.01									*2.90*
70	1.15	1.96	**1.53**	**0.36**	0.09	0.03										*5.11*
80	1.31	2.68	**2.15**	**0.68**	0.13	0.04	0.02	0.01								*7.02*
90	1.44	2.35	**1.51**	**0.37**	0.05		0.01									*5.73*
100	1.26	2.20	**0.99**	**0.26**	0.04	0.01										*4.75*
110	1.18	1.31	**0.58**	0.14	0.02											*3.21*
120	0.99	0.43	0.23	0.04												*1.70*
130	0.76	0.11	0.05													*0.93*
140																*0.00*
150																*0.00*
160																*0.00*
170																*0.00*
180																*0.00*
190																*0.00*
200																*0.00*
210																*0.00*
220																*0.00*
230																*0.00*
240																*0.00*
250																*0.00*
260																*0.00*
270																*0.00*
280																*0.00*
290																*0.00*
300																*0.00*
310	0.10															*0.10*
320	1.88	0.78	0.17	0.01												*2.83*
330	0.80	1.21	**0.57**	0.11	0.01											*2.69*
340	0.82	1.96	**1.84**	**0.64**	0.12	0.02										*5.40*
350	1.07	2.48	**3.21**	**1.47**	**0.49**	0.11	0.02									*8.85*
360	1.23	2.27	**2.21**	**0.99**	**0.40**	0.11	0.04	0.01								*7.27*
Tot.	*19.52*	*26.06*	*20.50*	*7.85*	*2.50*	*0.98*	*0.41*	*0.20*	*0.09*	*0.04*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*78.16*
Tot. Cumulato		*45.58*	*66.08*	*73.93*	*76.44*	*77.42*	*77.82*	*78.02*	*78.11*	*78.15*	*78.15*	*78.16*	*78.16*	*78.16*	*78.16*	

Figure 101 - Nearshore wave height (m): yearly time series – Pescara P2

CLIMA ANNUALE

	Classi di altezza d'onda significativa H_{m0} (m)															
Dir (°N)	0 0.25	0.25 0.50	0.50 1.00	1.00 1.50	1.50 2.00	2.00 2.50	2.50 3.00	3.00 3.50	3.50 4.00	4.00 4.50	4.50 5.00	5.00 5.50	5.50 6.00	6.00 6.50	> 6.50	Tot.
10	659	776	786	375	149	64	31	10	3	1						2 854
20	508	561	618	366	130	82	39	14	7	4						2 329
30	454	481	544	354	175	102	58	44	21	8						2 241
40	410	420	348	222	118	73	24	14	12	3						1 644
50	436	515	293	108	35	27	4	6	5							1 429
60	437	557	313	86	25	8	7	3		1						1 437
70	580	954	720	157	35	13	2									2 461
80	674	1 395	1 165	371	81	24	10	3								3 723
90	740	1 244	842	231	28	4	5	1								3 095
100	612	1 113	543	139	19	2	4									2 432
110	599	797	321	80	17	2										1 816
120	499	302	133	29	1											964
130	544	103	34													681
140																0
150																0
160																0
170																0
180																0
190																0
200																0
210																0
220																0
230																0
240																0
250																0
260																0
270																0
280																0
290																0
300																0
310	29															29
320	885	433	151	9	1											1 479
330	427	590	256	69	4											1 346
340	417	945	860	286	46	9										2 563
350	563	1 293	1 662	746	238	41	6									4 549
360	652	1 274	1 238	525	212	58	18	3	1							3 981
Tot.	10 125	13 753	10 827	4 153	1 314	509	208	98	49	17	0	0	0	0	0	41 053

CLIMA ANNUALE

	Classi di altezza d'onda significativa H_{m0} (m)															
Dir (°N)	0 0.25	0.25 0.50	0.50 1.00	1.00 1.50	1.50 2.00	2.00 2.50	2.50 3.00	3.00 3.50	3.50 4.00	4.00 4.50	4.50 5.00	5.00 5.50	5.50 6.00	6.00 6.50	> 6.50	Tot.
10	1.25	1.48	**1.50**	**0.71**	**0.28**	0.12	0.06	0.02	0.01							5.43
20	0.97	1.07	**1.18**	**0.70**	0.25	0.16	0.07	0.03	0.01	0.01						4.43
30	0.86	0.92	**1.04**	**0.67**	**0.33**	0.19	0.11	0.08	0.04	0.02						4.27
40	0.78	0.80	**0.66**	**0.42**	0.22	0.14	0.05	0.03	0.02	0.01						3.13
50	0.83	0.98	**0.56**	0.21	0.07	0.05	0.01	0.01	0.01							2.72
60	0.83	1.06	**0.60**	0.16	0.05	0.02	0.01	0.01								2.74
70	1.10	1.82	**1.37**	**0.30**	0.07	0.02										4.69
80	1.28	2.66	**2.22**	**0.71**	0.15	0.05	0.02	0.01								7.09
90	1.41	2.37	**1.60**	**0.44**	0.05	0.01	0.01									5.89
100	1.17	2.12	**1.03**	**0.26**	0.04		0.01									4.63
110	1.14	1.52	**0.61**	0.15	0.03											3.46
120	0.95	0.57	**0.25**	0.06												1.84
130	1.04	0.20	0.06													1.30
140																0.00
150																0.00
160																0.00
170																0.00
180																0.00
190																0.00
200																0.00
210																0.00
220																0.00
230																0.00
240																0.00
250																0.00
260																0.00
270																0.00
280																0.00
290																0.00
300																0.00
310	0.06															0.06
320	1.68	0.82	**0.29**	0.02												2.82
330	0.81	1.12	**0.49**	0.13	0.01											2.56
340	0.79	1.80	**1.64**	**0.54**	0.09	0.02										4.88
350	1.07	2.46	**3.16**	**1.42**	**0.45**	0.08	0.01									8.66
360	1.24	2.43	**2.36**	**1.00**	**0.40**	0.11	0.03	0.01								7.58
Tot.	19.28	26.18	20.61	7.91	2.50	0.97	0.40	0.19	0.09	0.03	0.00	0.00	0.00	0.00	0.00	78.16
Tot. Cumulato		45.46	66.07	73.98	76.48	77.45	77.84	78.03	78.12	78.15	78.15	78.16	78.16	78.16	78.16	

Figure 102 - Nearshore wave height (m): yearly time series – Pescara P3

Blue energy plants

The pilot projects to be selected and discussed will consider the future scenario as foreseen in the Structural Plan, rather than the current configuration. The perspective of new interventions and extensions is a good opportunity to promote the integration of blue energy in the new structures. In economic terms, this would concern an additional investment (generally estimated from 2% to 5% of the total budget) that, in the context of the total operation, looks more feasible and desirable.

The following figure highlights the most suitable sites for the installation of wave energy converters in piers and highlights the location of the new Maritime Station for a possible implementation of seawater-based heat pumps (in this case, river water also is an option).

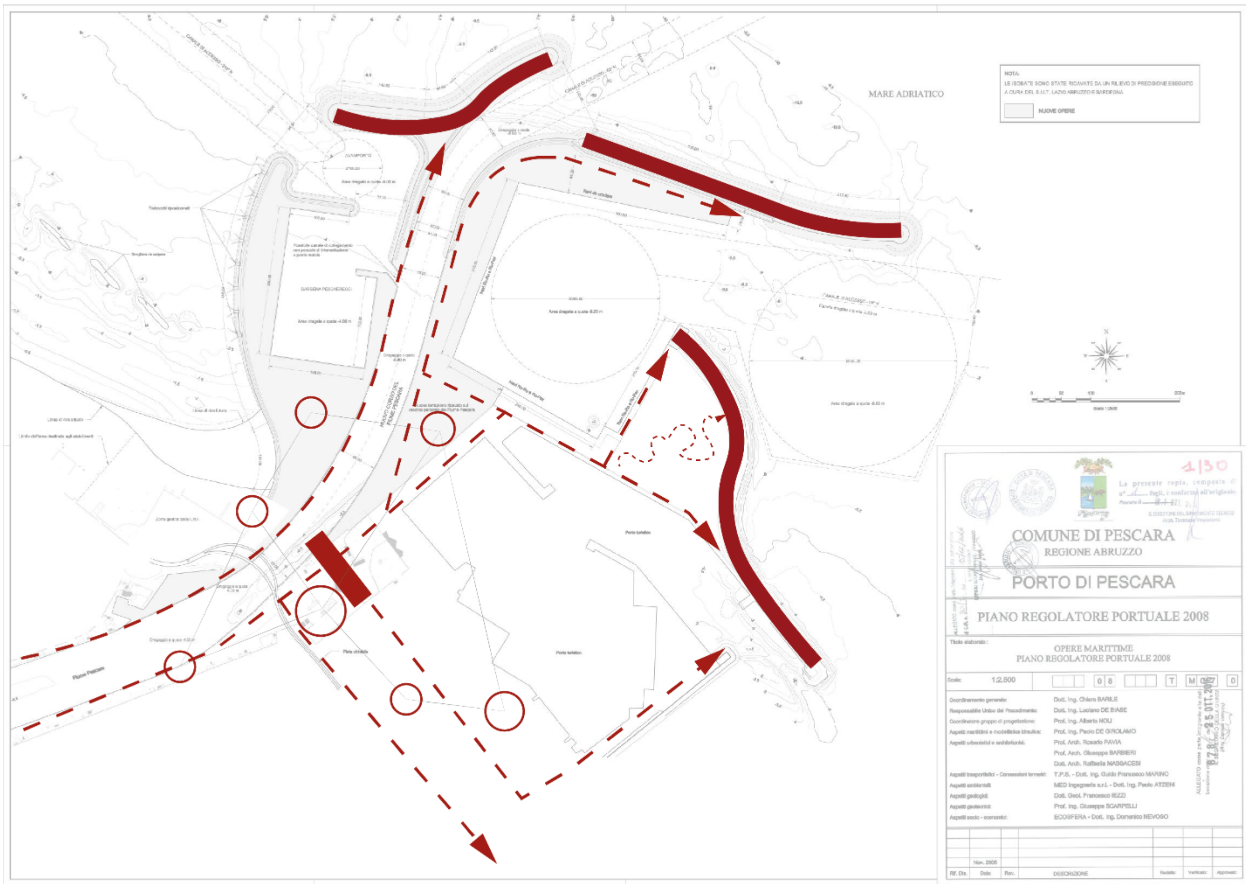


Figure 103 - Concept for the implementation of blue energies from the Structural Plan of Pescara Marina

In particular, the map above shows:

- marine energy plants:
    - wave energy converter on pier north (340 m);
    - wave energy converter on pier north-east (550 m);
    - wave energy converter on pier east (500 m);
    - the seawater-based heat pump (Maritime Station).

Regarding heat pump systems, one option concerns a detailed analysis of all the existing buildings in the Marina and their energy retrofitting through renovations and heat pump systems.

- Connections/interactions:
    - smart grid connections;
    - physical connections (e.g. multimodal pathways).
- Areal spots:
    - open-air functions;
    - spatial hotspots.

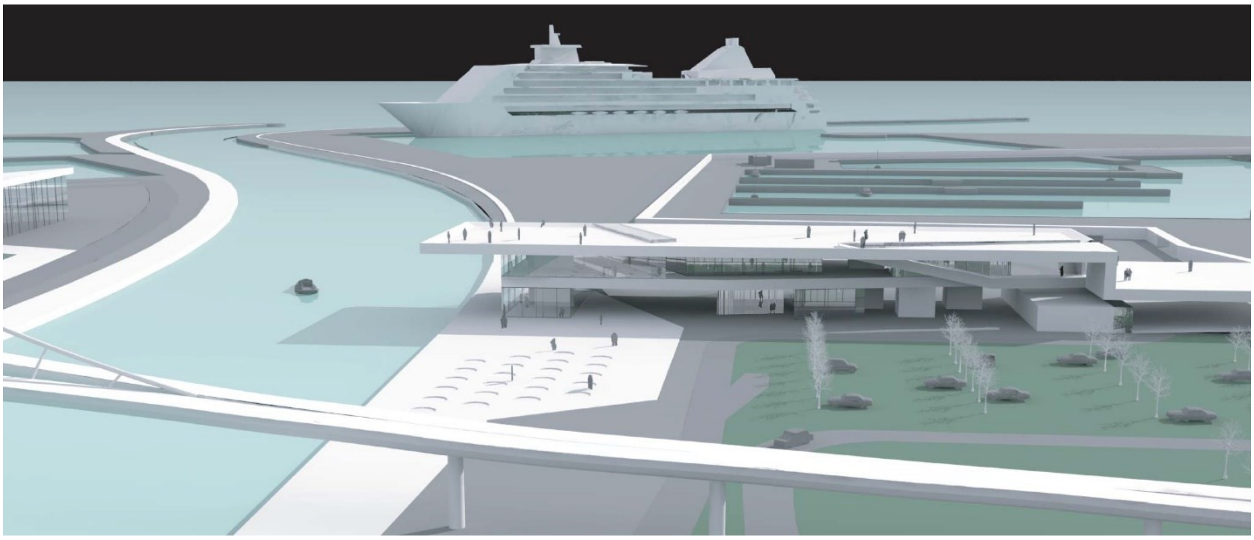


Figure 104 - New Maritime Station (source: Port Structural Plan)

Blue Energy production

As a preliminary estimate, we can hypothesize:

- combination of overtopping breakwaters and oscillating floaters along 1200 m of piers – estimated electricity production: 2.4-3.0 GWh per year (at least 200-250 MWh/yr per 100 m);
- seawater-based heat pump system for at least 20,000 m^3 of built volumes (e.g. new Maritime Station), heat energy demand: 20,000 kWh/yr; CoP>4; electricity demand: 5,000 kWh/yr fully provided by marine energy;
- the current energy demand of the Marina (including all services) is around 900 MWh/yr.

Port of Ortona

Description

The Port of Ortona is mainly a commercial port with a small touristic marina. Nowadays, the port has limited accessibility due to the dimension of piers and the wave motion within the port basin which represents a problem. The developmental strategy of the port is to enforce the commercial function and improve size and services to host bigger cargo.

Figure 105 - Port of Ortona: current state

Structural plan of the Port of Ortona

A Structural Plan for the Port of Ortona has been recently approved. A general strategy of complementarity of the regional harbours has been agreed and the Port of Ortona is designed to host commercial functions, besides a small marina. The new configuration was designed by prof. ing. Paolo De Girolamo and prof. ing. Alberto Noli includes a set of interventions that must be implemented:

- fixing of problems concerning the deposition of sand and the wave motion within the port basin through an extension of breakwater systems;
- enhancement of the commercial function and cargo services;
- extension of the port for the mooring of bigger cargos;
- extension of operational areas in the port (especially for cargo);
- improve internal connections while taking services separated for security reasons.

The port of Ortona has a relevant landscape issue because it can be seen from up the hill behind the city and therefore requires special attention.

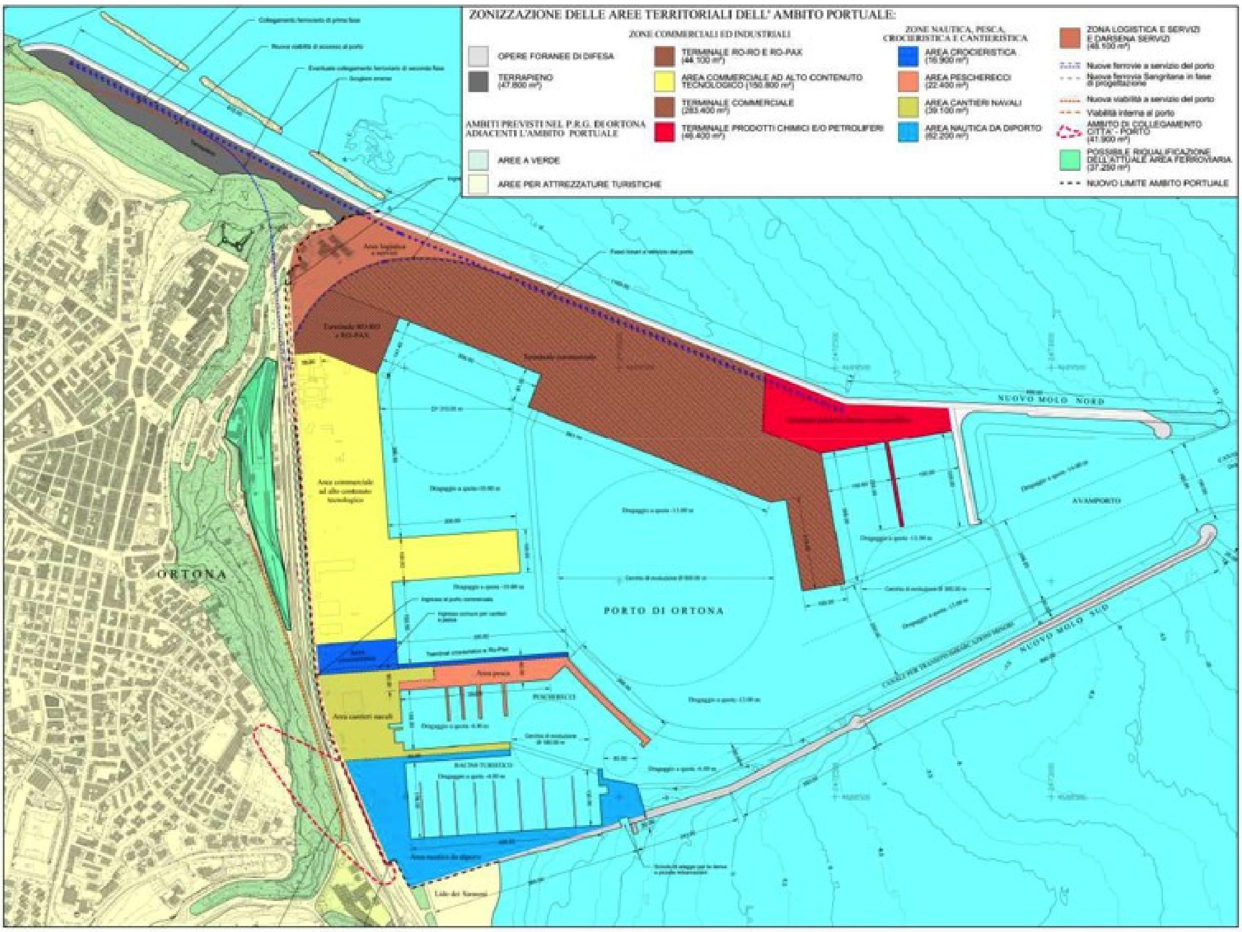


Figure 106 - Approved Structural Plan of the Port of Ortona

Climate and wave energy potentials

A detailed analysis of the marine energy potentials has been conducted by prof. ing. Paolo De Girolamo and included in the documentary material of the Structural Plan. Analysed parameters include wave energy, tidal changes, winds, and marine currents. Wave energy has been detected based on data collected by the buoys located in Ortona and Giulianova (providing together with a 20-year time series), as part of the National Wave Network managed by APAT. Data elaboration highlighted that:

- most intense waves (Hs>3.5 m) originate from between 310°N and 50°N;
- extreme events (Hs>2.0 m) have a low frequency (i.e., 3%);
- waves Hs>0.5 m originates from between 310°N and 50°N.

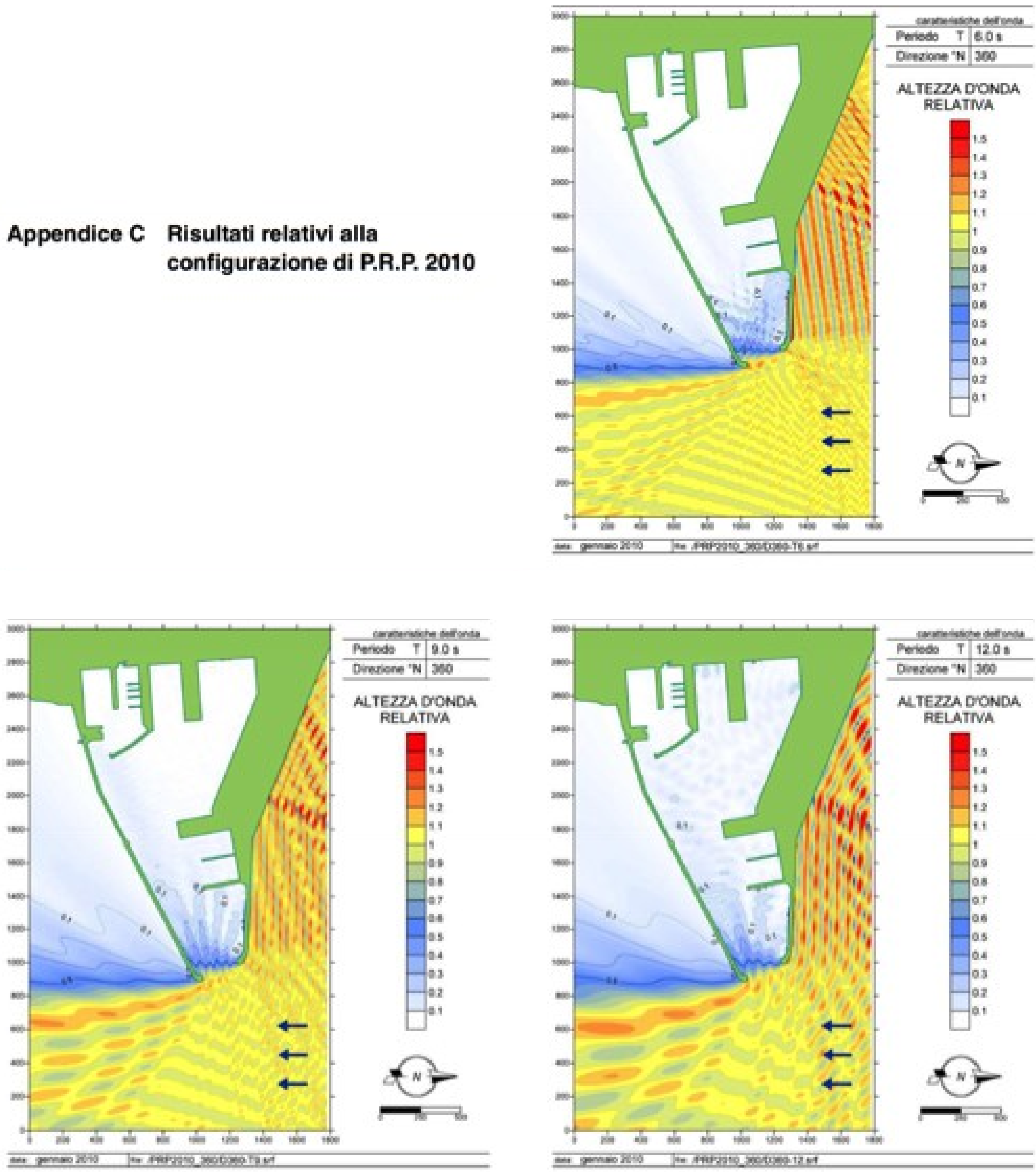


Figure 107 - Simulation model of wave motion (wave height) for the Port of Ortona. Source: Structural Plan. Maps refer to wave direction (360°N), periods (T): 6.0 s, 9.0 s, 12.0 s

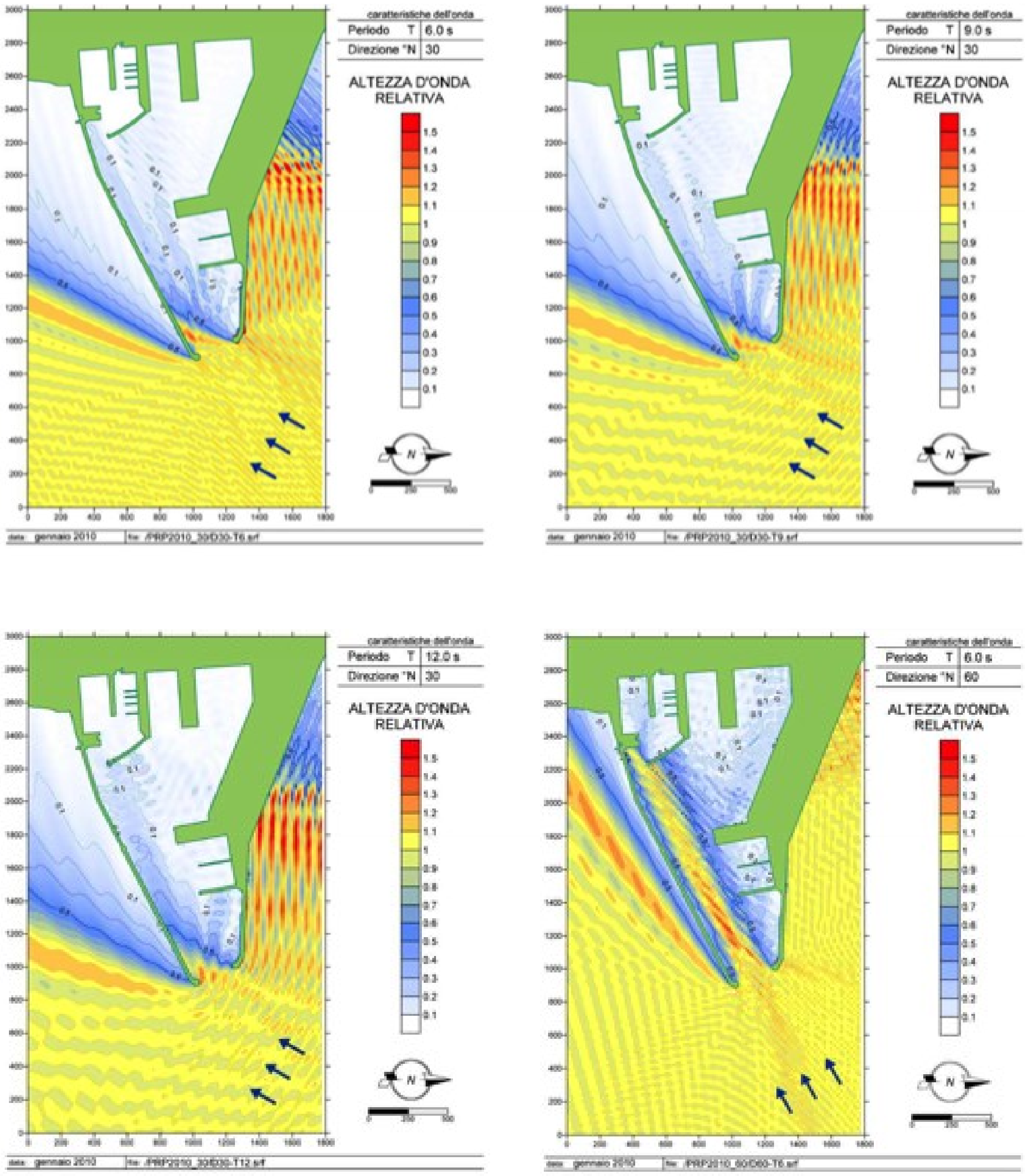


Figure 108 - Simulation model of wave motion (wave height) for the Port of Ortona. Source: Structural Plan. Maps refer to wave direction (30°N), periods (T): 6.0 s, 9.0 s, 12.0 s; wave direction (60°N), periods (T): 6.0 s

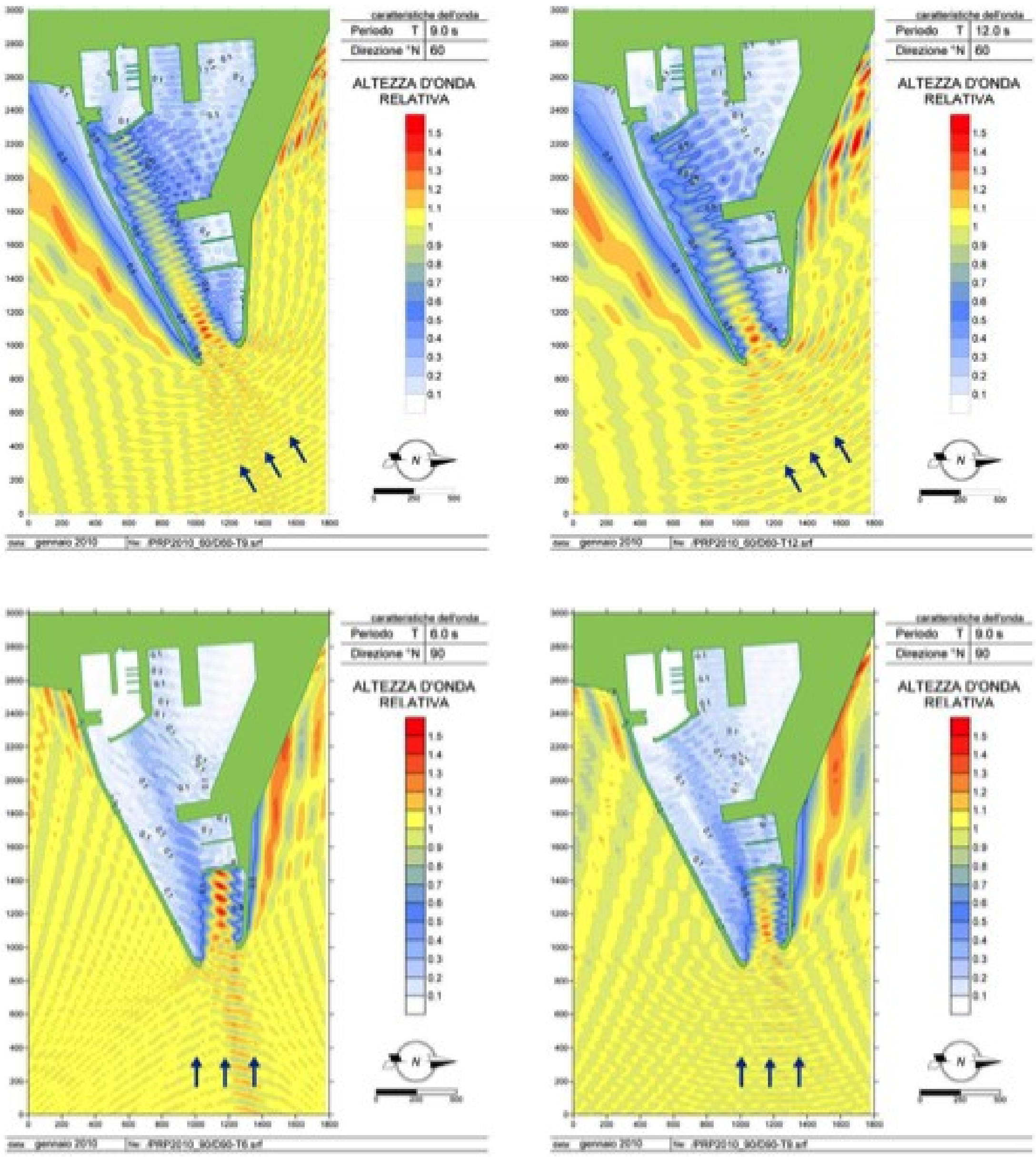


Figure 109 - Simulation model of wave motion (wave height) for the Port of Ortona. Source: Structural Plan. Maps refer to wave direction (60°N), periods (T): 9.0 s, 12.0 s; wave direction (90°N), periods (T): 6.0 s, 9.0 s

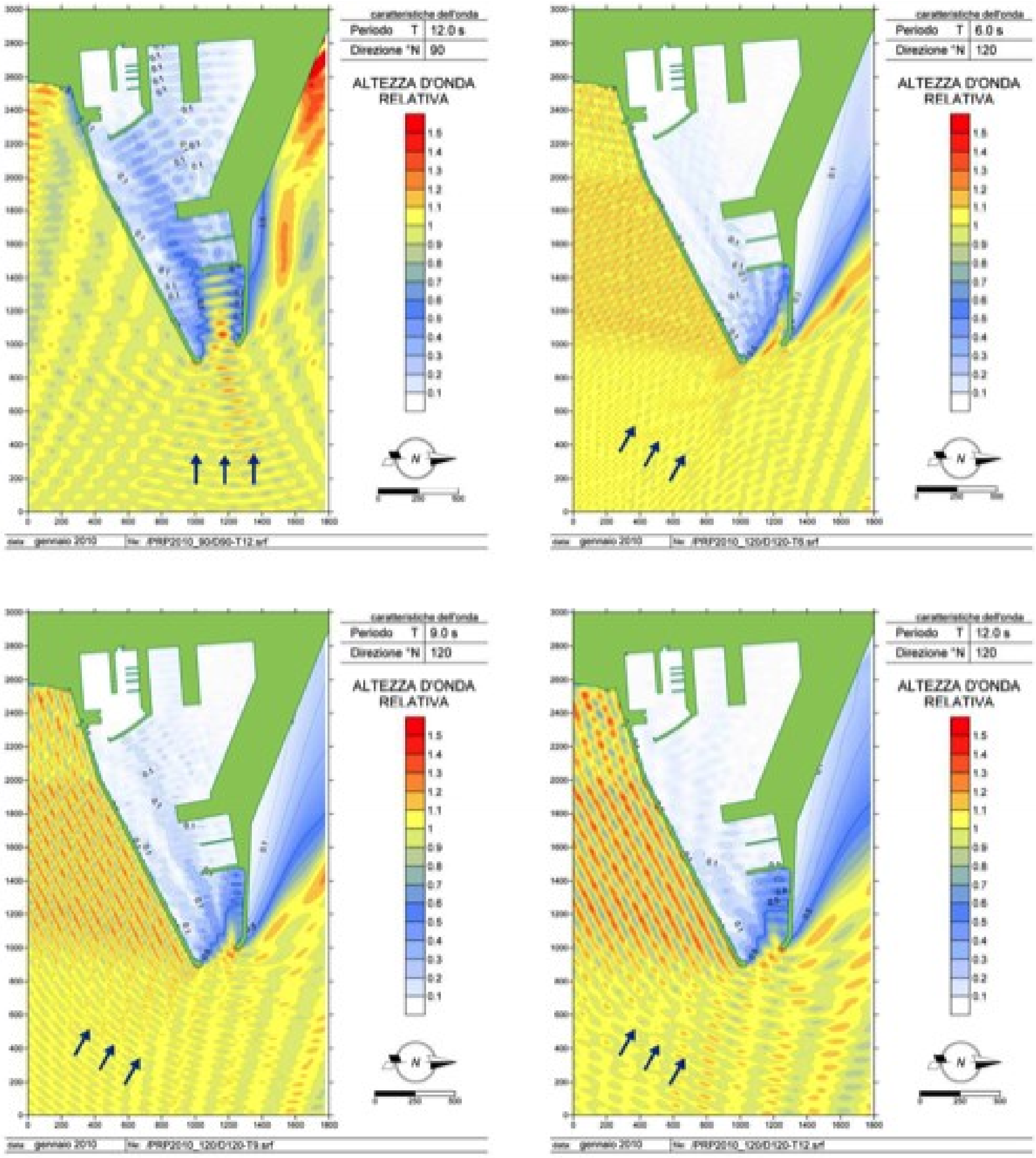


Figure 110 - Simulation model of wave motion (wave height) for the Port of Ortona. Source: Structural Plan. Maps refer to wave direction (90°N), periods (T): 12.0 s; wave direction (120°N), periods (T): 6.0 s, 9.0 s, 12.0 s

Blue energy plants

The pilot projects to be selected and discussed will consider the future scenario as foreseen in the Structural Plan, rather than the current configuration. The perspective of new interventions and extensions represent a good opportunity to promote the integration of blue energy in the new structures. In economic terms, this would concern an additional investment (generally estimated from 2% to 5% of the total budget) that, in the context of the total operation, looks more feasible and desirable.

The following figure highlights the most suitable sites for the installation of wave energy converters in piers.

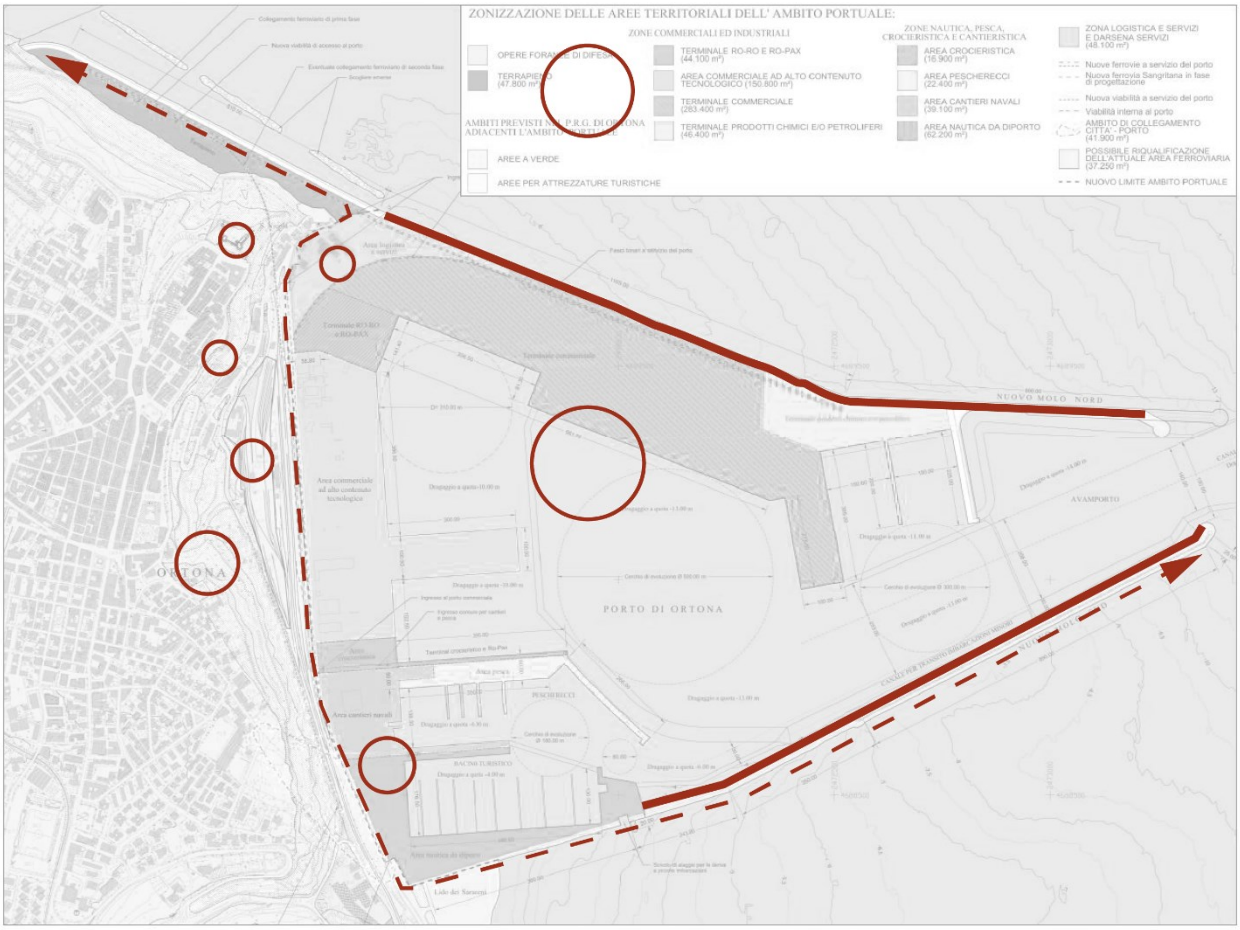


Figure 111 - Concept for the implementation of blue energies from the Structural Plan of the Port of Ortona

In particular, the map above shows:

- marine energy plants:
  - wave energy converter on pier north (1500 m);
  - wave energy converter on pier south (1000 m);
- connections/interactions:
  - smart grid connections;
  - physical connections (e.g., multimodal pathways);
- areal spots:
  - open-air functions;
  - spatial hotspots.

Blue Energy production

As a preliminary estimate, we can hypothesize:

- combination of overtopping breakwaters and oscillating floaters along 2500 m of a pier – an estimate of electricity production: 5.0-6.2 GWh per year (at least 200-250 MWh/yr per 100 m).

Vasto Marina

Description

The Marina of Vasto is a multifunctional port with commercial activities (e.g., transport of dry materials, vegetal oil, gasoil) and a touristic section. A few data follow:

- basin area: 198,000 m^2, of which 121,000 m^2 of port basin and 77,000 m^2 of entrance;
- water depth: 13.0 m at the entrance;
- water depth: from 6.0 to 8.0 m inside the basin;
- land area: 76,000 m^2;

- pier length: 1,000 m.

Figure 112 - Vasto Marina: current state.

Structural plan of Vasto Marina

A Structural Plan for the Port of Vasto has been recently approved including a set of interventions that have to be implemented:

- fixing of problems concerning the spill-over from northern breakwater systems;
- enhancement of the touristic function and related services in the marina;
- extension of the port for touristic and fishing functions and related services in the marina;
- the building of structures to host operators;
- environmental mitigation measures;
- increased accessibility.

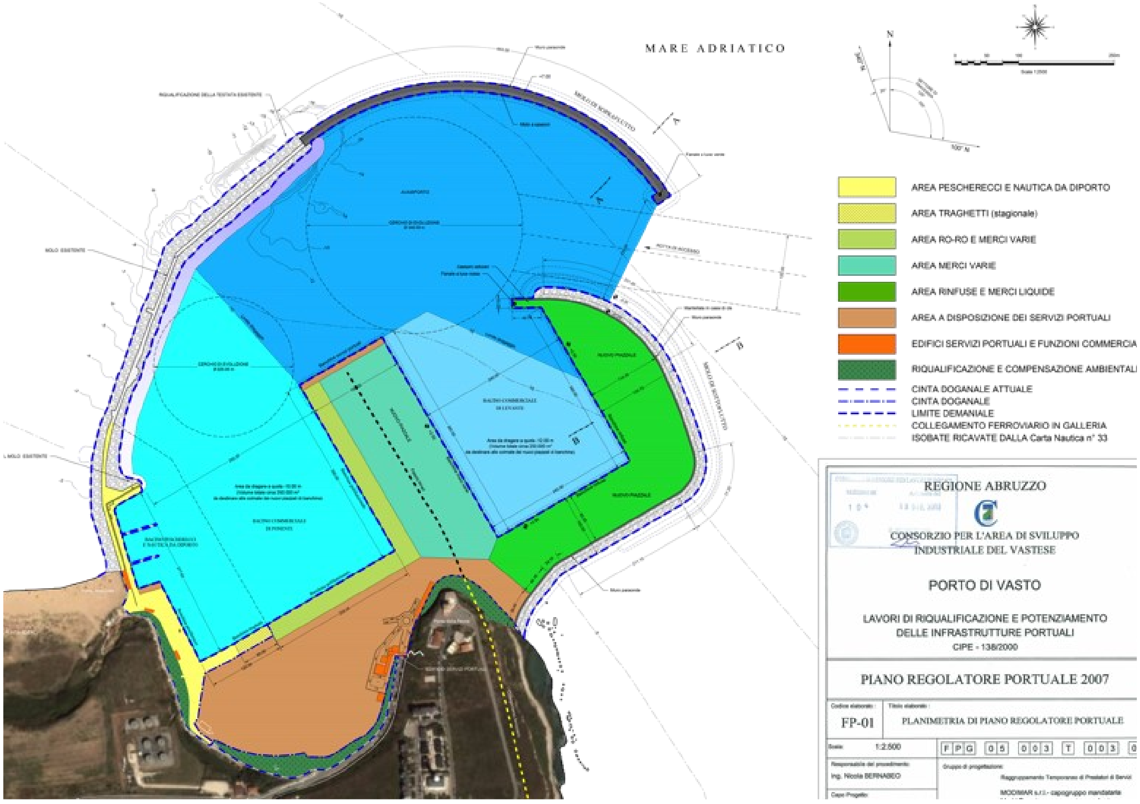


Figure 113 - Approved Structural Plan of Vasto Marina

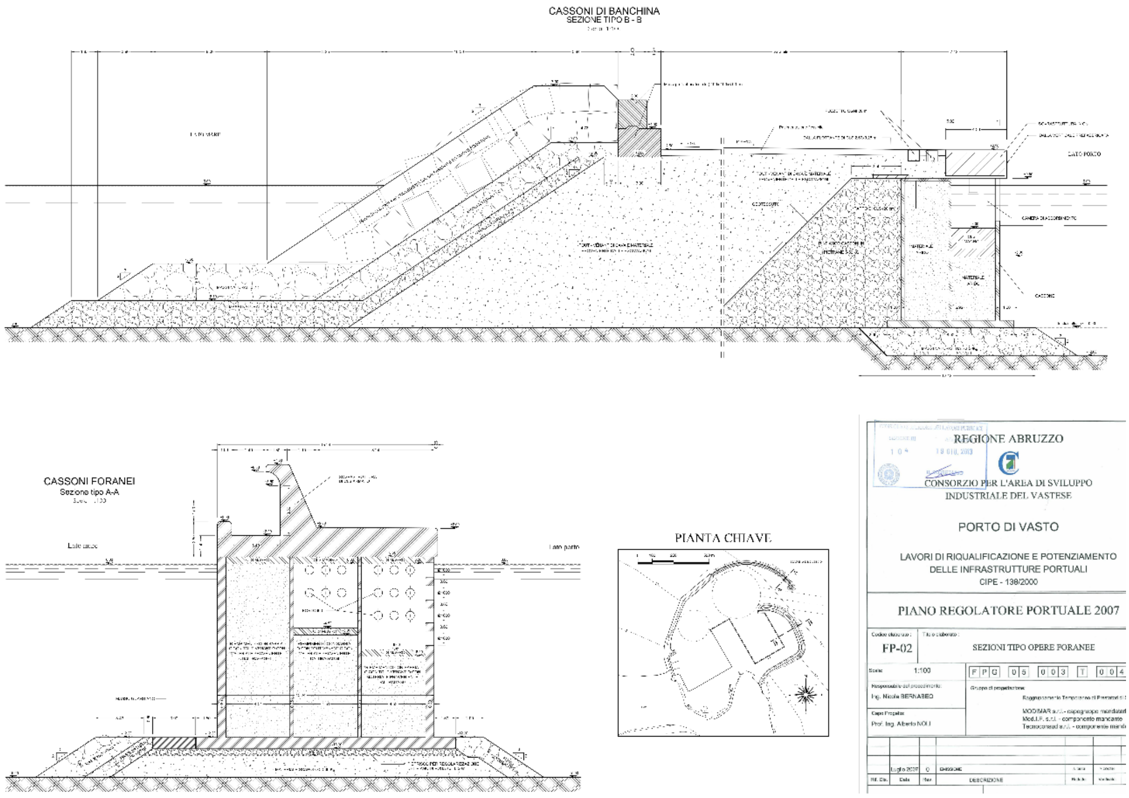


Figure 114 - Approved Structural Plan of Vasto Marina. Sections of breakwater systems

Climate and wave energy potentials

A detailed analysis of the marine energy potentials is included in the documentary material of the Structural Plan.

Data elaboration highlighted that:

- most intense waves (Hs>3 m) originate from between 350°N and 30°N;
- extreme events (Hs<5.5 m) have a low frequency (i.e., 0.8%);
- waves Hs>0.5 m originates from between 350°N and 30°N.

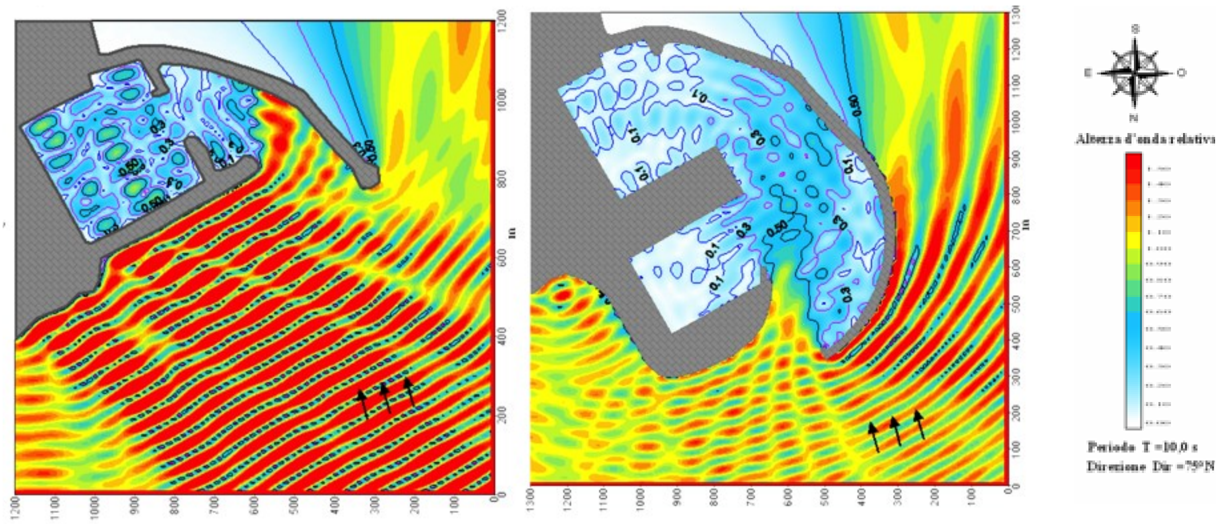


Figure 115 - Simulation model for wave motion: current vs. plan

Blue energy plants

The pilot projects to be selected and discussed will consider the future scenario as foreseen in the Structural Plan, rather than the current configuration. The perspective of new interventions and extensions represent a good opportunity to promote the integration of blue energy in the new structures. In economic terms, this would concern an additional investment (generally estimated from 2% to 5% of the total budget) that, in the context of the total operation, looks more feasible and desirable.

Marine energy plants may include:

- wave energy converter on pier north (600-800 m);
- wave energy converter on pier south (200-400 m).

Blue Energy production

As a preliminary estimate, we can hypothesize:

- combination of overtopping breakwaters and oscillating floaters along 800-1200 m of piers – estimated electricity production: 1.6-3.0 GWh per year (at least 200-250 MWh/yr per 100 m).

Suggestions for next Blue Energy pilots

Besides energy and technical design, the proposed pilots will investigate the visual and environmental integration of blue energy technologies as innovative elements of port landscapes.

The following images show some possible suggestions to integrate function (renewable energy production) with design and let blue energy technology work as elements of landscape identity in Mediterranean ports.

Figure 116 - Possible visual references for landscape projects of blue energy plants

3.8 Municipality of Ploče

The task is carried out within the COASTENERGY project to determine the potential for the use of marine energy in ports and urban coastal areas by examining possible conflicts and opportunities through the involvement of local and transnational stakeholders on both sides of the Adriatic Sea.

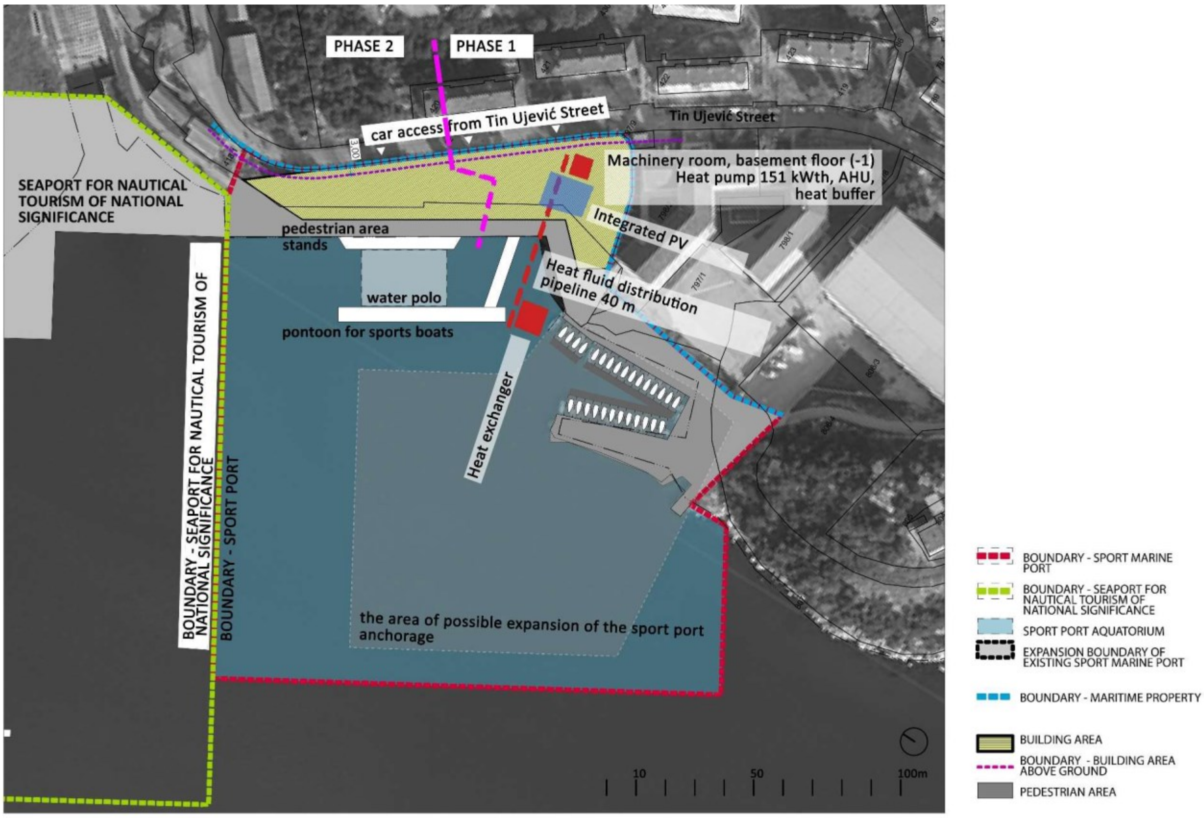
The City of Ploče has chosen the future building of the sport marine port in Ploče for this task. According to the conceptual design for the building of the sport marine port in Ploče, for the first phase of construction, a model will be made for the required energy for heating, cooling, ventilation, and lighting according to the conditions for nearly zero energy buildings. Energy simulations will be performed for different combinations of energy supply systems and the investment cost will be determined for:

- application of conventional heating/cooling sources;
- implementation of seawater heat pumps independently and in combination with solar panels;
- in a small part, the possibilities of implementing wave converters in the breakwater will be considered, with consideration of the preconditions for the implementation of wave energy technologies and possible next steps.

Through multicriteria analysis, the optimal technical solution will be selected that has the lowest total global cost (HRK/m^2) and the lowest primary energy (kWh/m^2), produces on-site energy from available renewable sources and achieves satisfactory internal thermal comfort.

Location

The new sport marine port area is situated in the NW end of Ploče city area (43°03'28.0"N, 17°25'42.7"E), in the area previously used as a military-technical workshop. The area is in the cadastral municipality of Ploče and includes parts cadastral parcels no. 418/1, 418/2, 806/1, 807, 797/1 and 797/2. The building is located on part of cadastral parcel no. 418/1, while other parts of the project (coast and promenade) are located on the other listed parcels. To perform the project, it will be necessary to carry out parcelling, which will harmonize the scope of the project with the situation in the cadastre.



Legal-regulatory framework

For the implementation of the project, it is necessary to meet the conditions in the field of construction, environmental protection and use of the maritime property. The use of sea thermal energy does not have special treatment in Croatian legislation (special regulation, chapter, or provision of law) nor special or simpler approval procedures are provided for such projects. Also, there is no single point in charge of issuing all relevant information and performing or coordinating administrative procedures related to the use of marine energy. Therefore, it can be said that the use of sea thermal energy is subject to general regulations relating to other renewable energy projects (which includes sea energy), and the administrative procedure for issuing permits for energy use should include a few institutions at state and local level. Nevertheless, the peculiarity of arranging these projects stems from the fact that they are planned and implemented on the maritime demesne, which in the Croatian legal system enjoys a special ownership status and emphasized environmental protection.

The permitting process can be divided into interrelated, intertwined and agreed phases such as project planning and environmental assessment of the project, determining the spatial acceptability of the project and special conditions for connecting infrastructure, obtaining a concession for the use of maritime demesne, approval of construction and construction, issuing permits for performing energy activities, etc. Each of these phases will be described below with a brief overview of the relevant regulations, the necessary acts and the actions required to obtain them.

Acceptability of the environmental procedure

The area of environmental and nature protection in the Republic of Croatia is regulated by the Environmental Protection Act (Official Gazette no. 80/13, 78/15, 12/18, 118/18) and the Nature Protection Act (Official Gazette no. 80/13, 15/18, 14/19, 127/19). The Environmental Protection Act specifically recognizes and elaborates the protection of the sea and the coastal area. The Nature Protection Act regulates the assessment of the acceptability of a plan, program, or intervention for an ecological network.

According to Regulation on Environmental Impact Assessment (Official Gazette no. 61/14, 3/17), the implementation of environmental impact assessment is mandatory for 14 power plants greater than 100 MW, while for plants to produce electricity, steam and hot water with a capacity of more than 10 MW, it is necessary to conduct an assessment of the need for environmental impact assessment for which the Ministry of Economy and Sustainable Development (MESD) is responsible.

Conclusion: The seawater intake for the Sports Port of Ploče has a heat pump system whose power is lower than those specified in the Regulation, so it is not mandatory to carry out procedures in the field of environmental and nature protection.

Analysis of natural conditions of the location and technology of using sea energy

The city of Ploče is characterized by features of a Mediterranean climate with mild and rainy winters and hot and dry summers. Natural geographical features, such as the Neretva River valley, which extends deep into the interior, the proximity of the mouth of the Neretva River, the karst edge, the vicinity of the sea, the configuration of the terrain, the relative natural saturation from the sea influences have affected specific climatic local features, thus shaping the microclimate of individual areas. In the following, the natural conditions characteristic of the observed area of construction of the sports port in Ploče are analysed and presented, including wind, waves, sea currents and bathymetric data. In addition, the available technologies for the use of marine energy are described, as well as the potential for their application considering the natural potential of the site.

Analysis of wind potentials

The wind analysis is based on Global Wind Atlas, which is a free, web-based application developed to help policymakers, planners, and investors identify high-wind areas for wind power generation virtually anywhere in the world and then perform preliminary calculations. The current version of the Global Wind Atlas (GWA 3.0) is the product of a partnership between the Department of Wind Energy at the Technical University of Denmark (DTU Wind Energy) and the World Bank Group (consisting of The World Bank and the International Finance Corporation, or IFC). The Global Wind Atlas has global onshore coverage and offshore coverage up to 200 km from the shoreline. The wind resource mapping is given at 10, 50, 100, 150 and 200 m above ground/sea with the horizontal grid spacing of 250 m. Users can assess the wind resource for a given point, over a custom area, or within a country or first administrative unit (state/province/etc.). GIS data for all layers are available for download as well as WAsP LIB files. The referent value presented by the GWA is the mean value for 10% of the windiest areas. Also, it is possible to get averages of over the whole surface (100% area) up to the 2% of the windiest areas, which can be considered as a maximum value for a chosen location. Additionally, the data obtained from GWA do not refer to a chosen point but to an area of dimensions 3 km ×3 km (9 km2), where the selected point is the centre of the area. The analysis of the wind over the described platform was performed for the city of Ploče, more precisely the area of the future sports port in Ploče. The table below (Table 4-1) shows two types of data: mean wind speed and mean wind power density for 100%, 10% and 2% of the windiest area in the range from 10 m to 100 m above sea level. It is important to note that the wind measurements that are the foundation of GWA were conducted in the period from 2008 to 2017. Therefore, GWA typically displays an inter-annual average of wind speed and wind power density.

Altitude [m]	Share of the windiest area [%]	Mean wind speed [m/s]	Mean power density [W/m²]
10	2	5,48	346,76
50	2	7,28	656,23
100	2	7,86	695,87
10	10	4,73	225,32
50	10	6,58	493,12
100	10	7,40	584,20
10	100	3,25	92,99
50	100	5,10	248,15
100	100	6,05	336,12

Figure 117 - Average inter-annual wind speed and wind power density in the sports port in the city of Ploče

Analysis of wave energy

The wave analysis is based on a publicly available database developed within the Maestrale project (Sustainable Blue Energy in the Mediterranean). Maestrale was conducted in the period 2014-2020 as an Interreg MED 2014-2020 Programme financed by the European Regional Development Fund. The University of Siena (UNISI) was coordinating a consortium of 10 partners from Italy, Greece, Malta, Spain, Portugal, Croatia, Slovenia, and Cyprus. At the time, the limited progress in concrete initiatives and operating plants in the Mediterranean area has been detected despite numerous academic and technical studies already conducted in the field of offshore renewable energy. Therefore, the Maestrale project has been launched to lay the foundation for a strategy in maritime renewable energy deployment in the Mediterranean. The project partners cooperated to analyse the maritime renewable energy potentials in their countries with regards to their physical, legal, technological, economic, and social contexts. The main achievement of Maestrale is in the formation of a network of local enterprises, public authorities, knowledge institutions and citizens with the common goal of planning plan concrete strategies for maritime energy growth. A set of pilot projects in each participating country was envisaged as a means for awareness-raising and social acceptance to increase the feasibility of future maritime energy initiatives. The Maestrale database gathered existing data collections provided by project partners and provides access to open geographical data on maritime renewable energy potential. The database provides reliable and up-to-date informative support to decision-makers and investors, setting the basis for the development of maritime energy initiatives in the Mediterranean area. The database link is http://maestralewebgis.unisi.it/.

Figure 118 graphically shows the inter-annual average of the wave power for the observed area. In the figure shown, the average wave power in the analysed area does not exceed the value of 0.1 kW/m. The inter-annual average of the wave height for the analysed area does not exceed the value of 0.3 m, which can be seen in Figure 119, while the inter-annual average of the wave period does not exceed the value of 3.4 s (Figure 120).

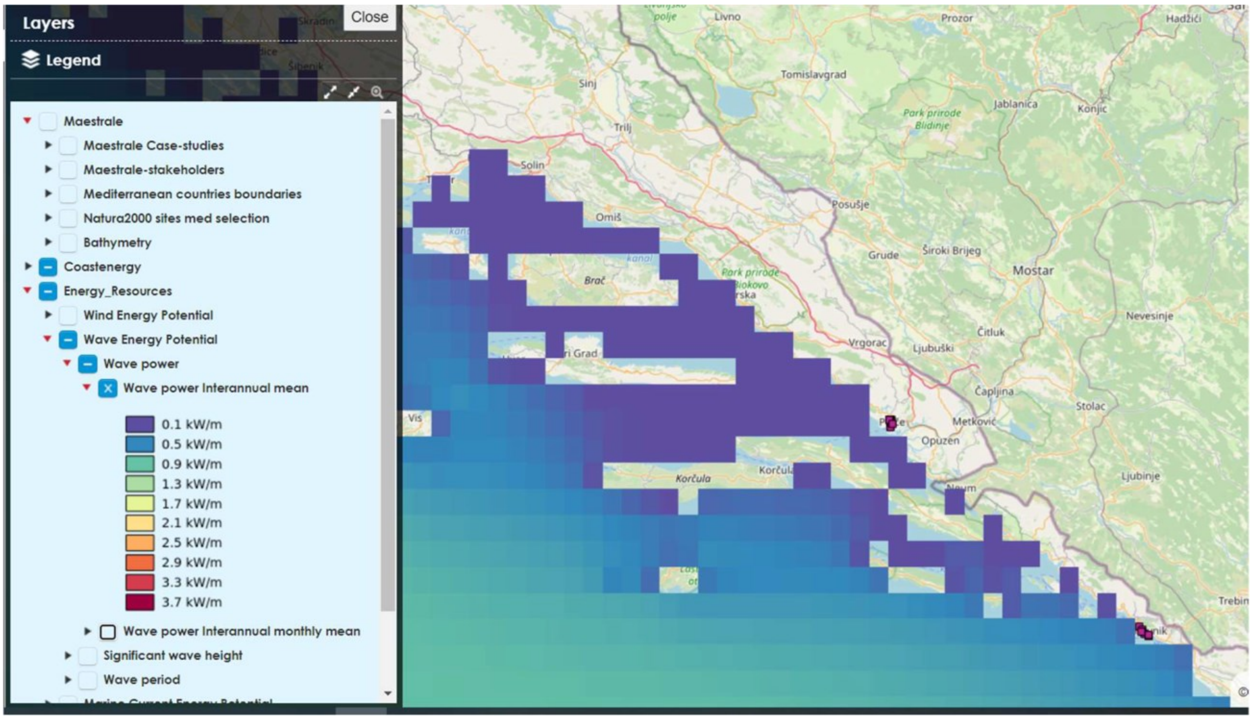


Figure 118 - Inter-annual average of wave power around the city of Ploče

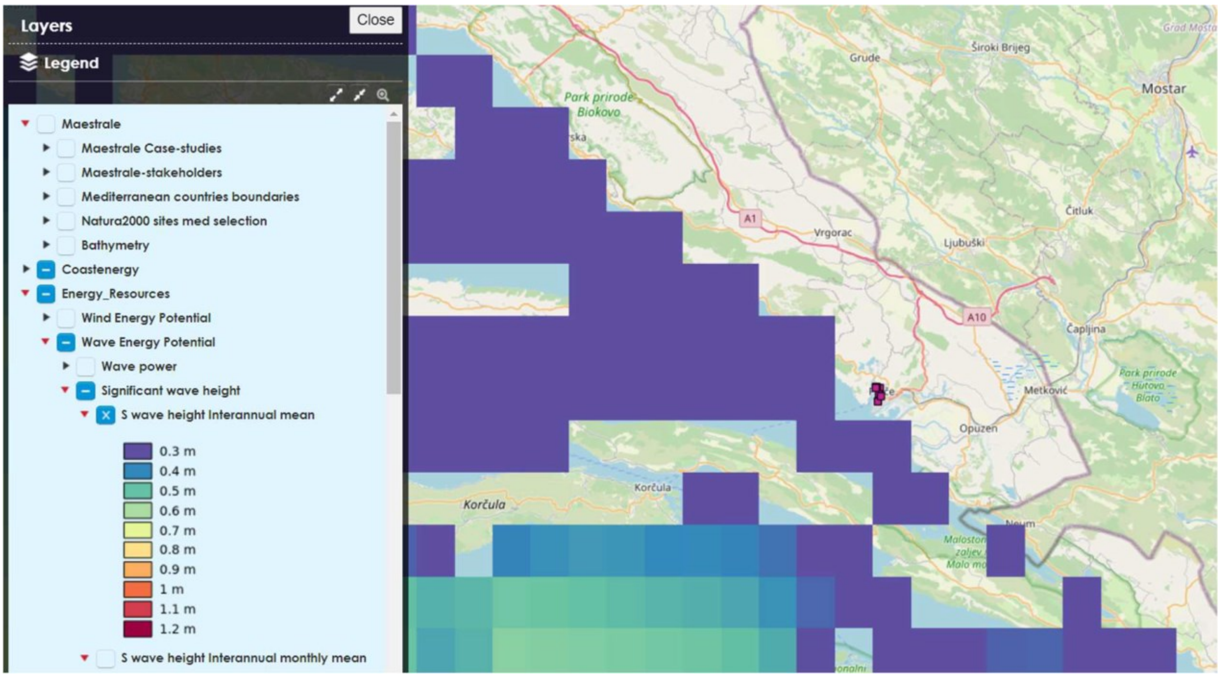


Figure 119 - Inter-annual average of the wave height around the city of Ploče

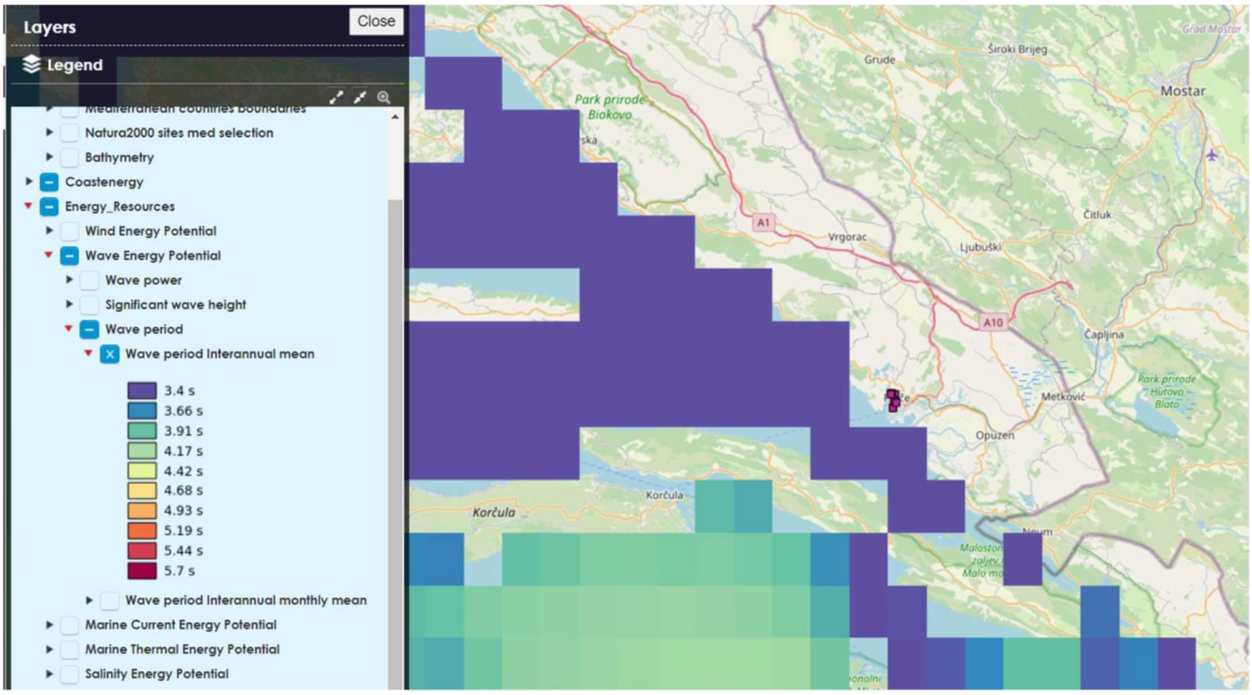


Figure 120 - Inter-annual average of the wave period around the city of Ploče

On the maps shown in the figures above, it is possible to select any place and get the average monthly values of power, height, and period of the wave. Given the unavailability of data near the sports port, the nearest location for which monthly data are available was selected, and these are shown in the table below (Figure 121).

Month	Wave power [kW/m]	Wave height [m]	Wave energy period [s]
January	0,0291	0,1507	2,6087
Februray	0,0316	0,1636	2,4086
March	0,0235	0,1410	2,4053
April	0,0170	0,1187	2,4593
May	0,0131	0,1030	2,5065
June	0,0099	0,0889	2,5494
July	0,0123	0,1006	2,4859
August	0,0112	0,0959	2,4883
September	0,0096	0,0876	2,5641
October	0,0145	0,1074	2,5695
November	0,0213	0,1306	2,5562
December	0,0195	0,1262	2,5005

Figure 121 - Monthly averages of wave power, wave height and wave energy period around the city of Ploče

Analysis of sea thermal energy

Sea temperature data were obtained from: https://seatemperature.info/. According to the above data, the average annual sea temperature is 18.78°C. The table below shows the average, minimum and maximum monthly sea temperature in Ploče, which were calculated based on the data over the past 10 years.

Month	Average temperature [°C]	Minimum temperature [°C]	Maximum temperature [°C]
January	14,1	12,6	16,1
Februray	13,2	11,3	14,3
March	13,3	12,0	14,7
April	14,9	12,8	18,8
May	18,4	15,4	23,1
June	22,4	18,3	25,8
July	24,7	22,1	28,2
August	25,3	22,8	28,3
September	23,2	19,3	26,5
October	20,7	17,2	23,7
November	18,7	16,2	21,6
December	16,3	13,8	18,9

Figure 122 - Average, minimum and maximum monthly sea temperature in Ploče

Analysis of sea currents

The kinetic energy of the moving seawater is governed by the mutual moon and sun gravitational attraction, and the earth's rotation. It is also strongly affected by its 26 relative positions as well as by the coastal geography, seabed bathymetry, and movements of large volumes of sea waters around the seas and oceans. Consequently, the tidal energy potential is distributed quite unevenly around the globe. The tidal range of the Mediterranean Sea, including the Adriatic Sea, is almost negligible as compared to the tidal ranges typical for areas like Canada, the United Kingdom, Portugal, Chile, China, and Australia that can reach up to 17 m, resulting in seawater flow rates of up to 4 m/s. An intensive and systematic geophysical research of the Adriatic Sea as a closed system, carried out between 2002 and 2006, included extensive data collected using Automated Meteo-Oceanographic Station and Acoustic Doppler Current Profilers. It was ascertained that the sea currents reach about 0.2 m/s in the Split archipelago, 0.32 m/s at the open sea off the Dugi Otok Island, and approximately 0.1 m/s at the North Adriatic. However, a necessity for more detailed databases was recognized and a detailed analysis of the tidal currents in the Adriatic Sea as measured by surface drifters was performed. The Adriatic Sea surface was well covered, except between Croatian islands. It was concluded that the tidal forcing is strongly affected by the oscillating sea level at the Otranto Channel and that the governing tidal effects correspond to the semidiurnal lunar tide (M2), the semidiurnal solar tide (S2), and the lunisolar declination (K1) resulting with sea current flow aligned with the main axis of the Adriatic Sea. The flow strength is increasing near the Istrian Peninsula reaching the top depth-averaged velocity of about 0.066 m/s (M2) being the peak flow velocity detected by drifters, Figure 123.

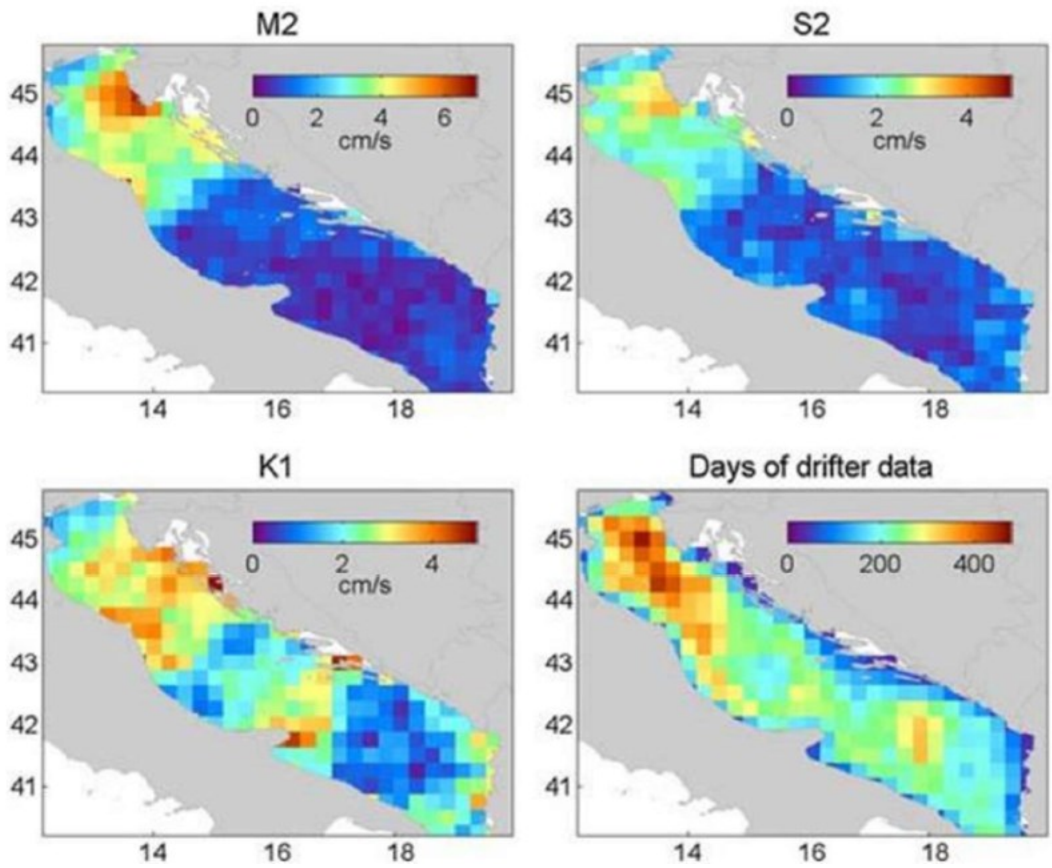


Figure 123 - Tidal current velocity in the Adriatic Sea, M2, S2, and K2 component; days of drifter data (Poulain, PM (2013) Tidal currents in the Adriatic Sea as measured by surface drifters, Journal of Geophysical Research, 118, pp. 1434-1444.)

A more detailed view of the sea currents of the Adriatic Sea, both in territorial and data terms, is available in a prognostic format based on the application of ROMS (Regional Ocean Modelling System) numerical model which, with Boussinesqu approximation, solves Navier-Stokes equations on a given geographic network (Source: https://bora.gekom.hr/karte.php?page=more). The model, applied in the case of the Adriatic Sea, considers the 7 lunisolar components of tides, freshwater inflows, and the influence of wind on the characteristics of surface currents. In this sense, the basic results of the model are a five-day forecast of the speed and direction of surface currents, as well as the average value of the vertical profile of sea currents. An example of prognostic data of surface current characteristics and vertical profile of sea currents is shown in the figures below for the case of the southern Adriatic.

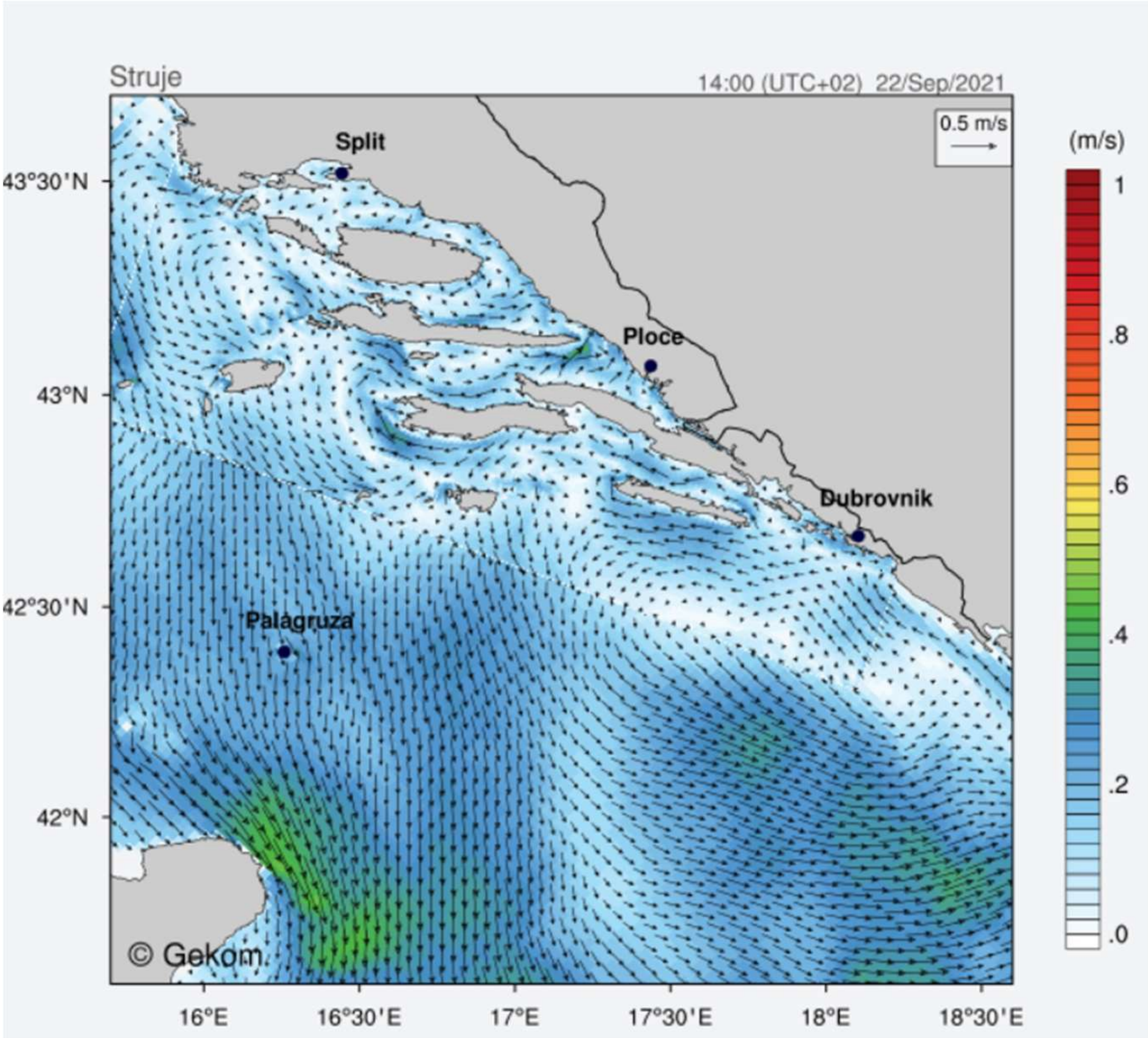


Figure 124 - Surface velocity and direction of sea currents in the southern Adriatic

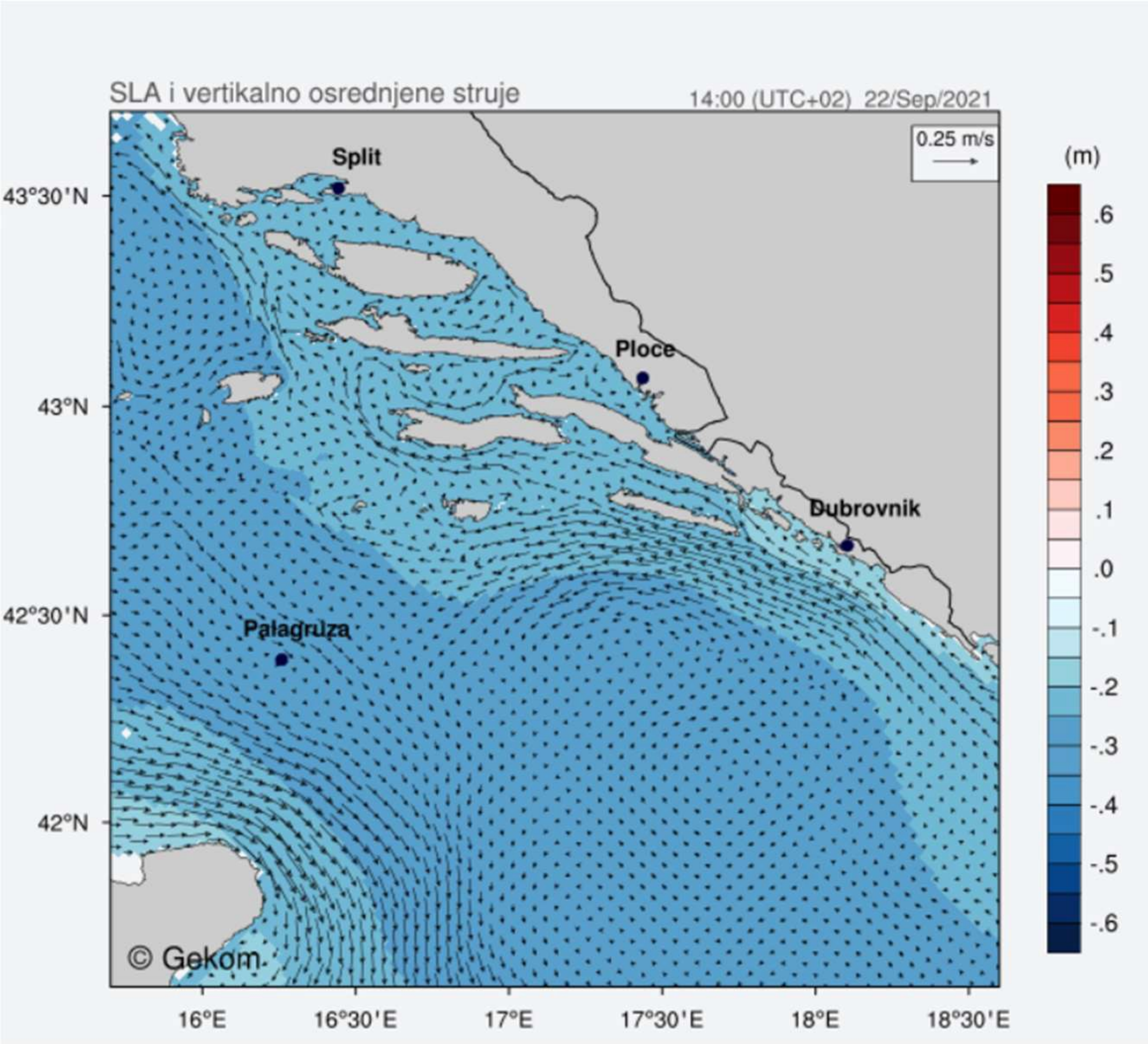


Figure 125 - Average speed and direction of the vertical profile of sea currents in the southern Adriatic

Bathymetric data

The Adriatic Sea's average depth is 259.5 meters, while its maximum depth of 1,233 meters is placed at its southern part. Bathymetric data for the area of the sports port in Ploče was taken from the database of the European Marine Observation and Data Network (EMODnet) and are graphically shown in Figure 126. From the graphic presentation, it is possible to notice that the sea of the coastal area of the city of

Ploče is quite shallow, and is approximately 5 m, while the depth of the sea at 50 m is approximately 13 m.

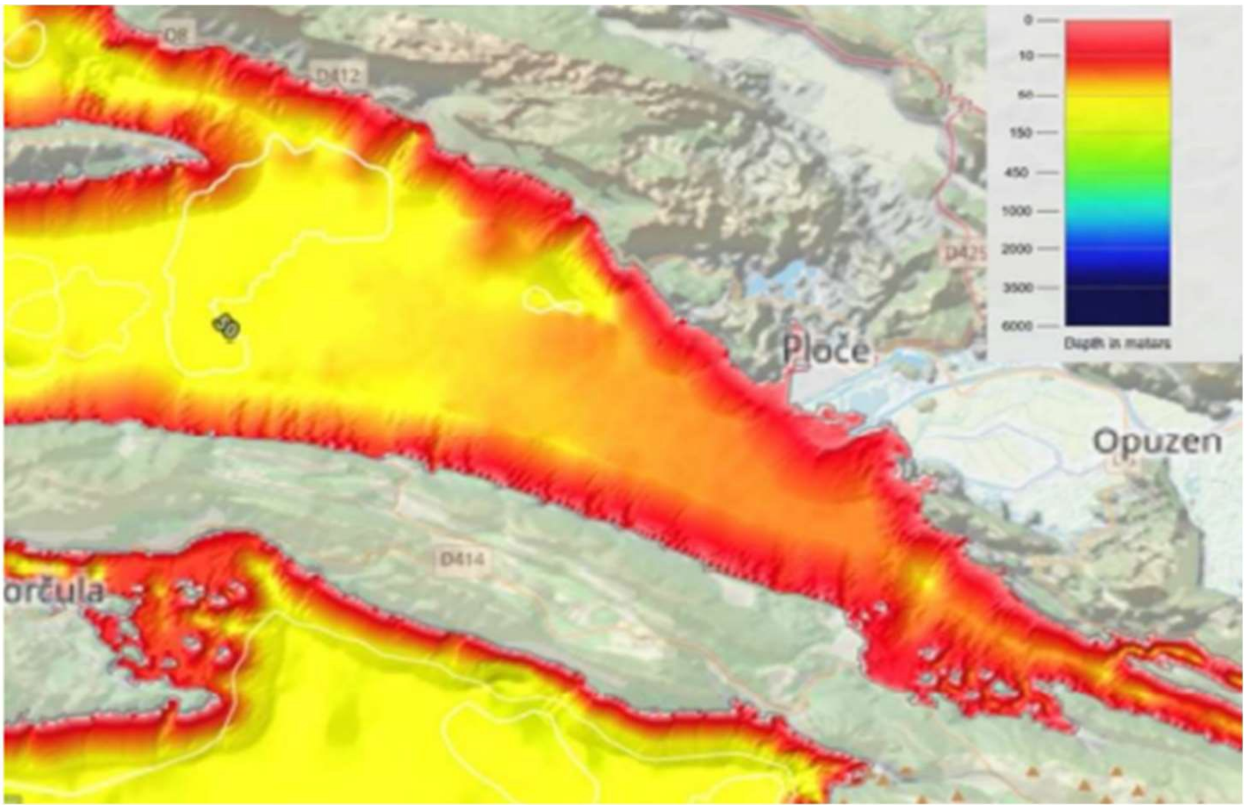


Figure 126 - Bathymetric data for the area near the city of Ploče

Technologies for the use of marine thermal energy

The seawater thermal energy can be used for heating and cooling of facilities along/near the shore by implementing heat pump systems with seawater as a heat storage tank. Seawater heat pump systems are systems in which the heat pump uses the seawater as a heat source or sink, i.e., a heat storage tank - in the heating mode, the system uses the energy of the seawater as a renewable heat source, while in the cooling mode it transfers the heat taken from the space to the seawater as a heat sink. Due to the seawater corrosivity, seawater does not transfer heat directly via a heat pump evaporator, but previously via a corrosion-resistant intermediate exchanger to freshwater which then flows to the evaporator. The heating energy on the evaporator is then transferred to the refrigerant and rises to a higher energy level, and 30 is then transferred to the heated space. The reverse process applies to the operation of the heat pump in cooling mode.

There are two versions of the heat pump system with seawater as a heat storage tank: open and closed version (Figure 1). In the case of an open system, the seawater is pumped directly from a certain depth through a pipeline laid into the sea, which returns it, while in the closed version the glycol mixture exchangers are placed in the sea without seawater contact with the heat pump system. Both designs ensure equal system efficiency, but the closed version is initially more expensive because it involves more extensive installation work. On the other hand, the application of open versions is limited in areas with very cold climates as water freezing can occur, as well as the pipelines themselves laid in the sea.

Figure 127 - Open (left) and closed (right) version of the seawater heat pump system

The target seawater intake depth for the operation of seawater heat pumps is 0 – 20 m. The higher the depth of the sea, the lower the annual water temperature changes. The considered depth of the sea is considered as the surface layer of the sea, and the temperature changes in this layer are called thermohaline properties of the sea. An example of the sea temperature profile for the Gargano - Split route in the summer and winter months is shown in the figure below. It can be observed that at a sea depth of 20 m the sea temperature varies in the range of 13 °C to 20 °C for the Split location, which is an annual temperature change of only 7 °C.

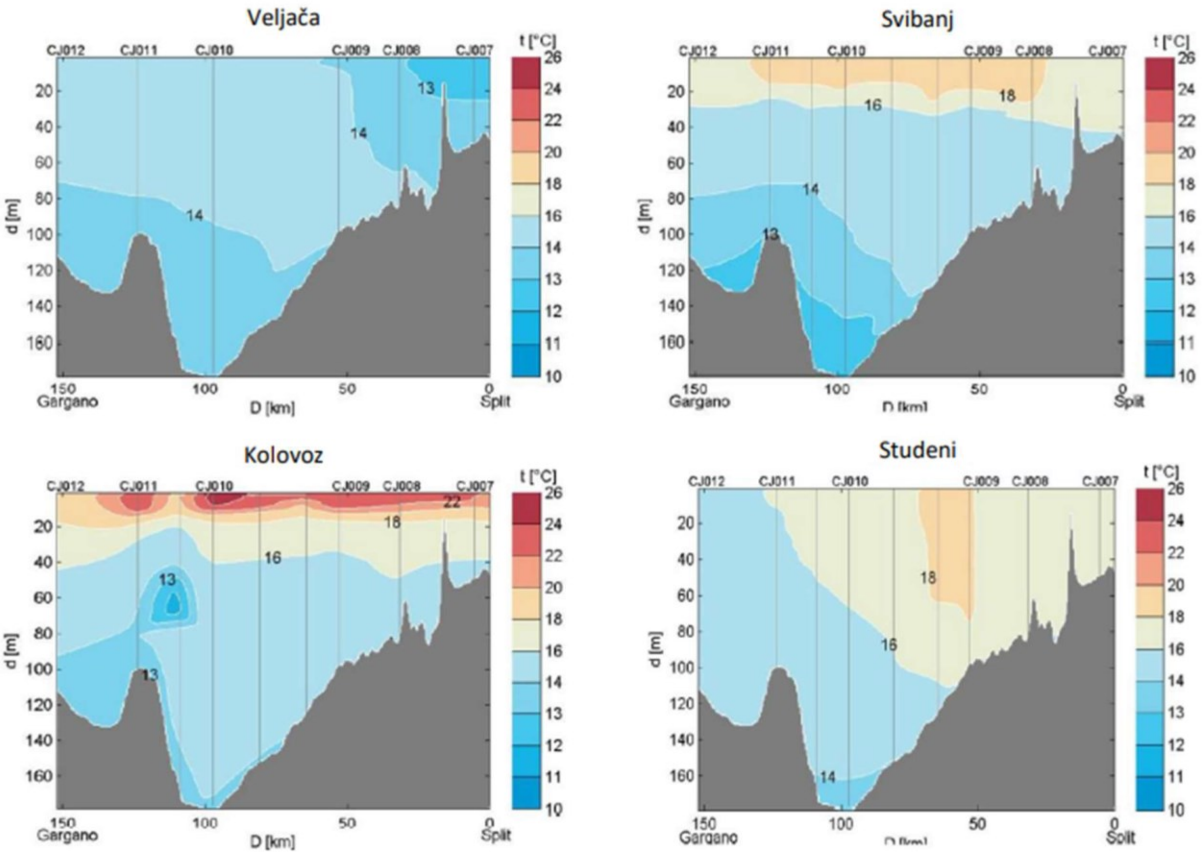


Figure 128 - Gargano-Split Sea temperature profile depending on sea depth in summer and winter

Seawater intake is one of the most important parts of a seawater heat pump system since the continuous and stable operation of the heat pump depends on continuous, stable, and sufficient seawater inflow. The characteristic seawater intake system consists of a suction pipeline and its associated suction port and a protective grille around it, pumps, and a return pipeline. Currently, there are two ways of seawater intake for the heat pump operation: direct seawater intake at a certain distance from the coast, and seizure of water from wells by the sea, i.e., on the coast itself. Direct seawater intake involves the intake of seawater directly from the sea at a certain depth and distance from the coast. It consists of a suction pipeline and its associated suction port and a protective grid around it, underwater pipelines that conduct seawater to the corrosive resistant heat exchanger and back to the sea, pumping stations and a re-mixer of seawater, from which heat is taken over, with water in the sea. Subsurface seawater intake from wells by the sea is groundwater abstraction from aquifers only a few meters below Earth's surface on or along the coast. This groundwater may be the result of infiltration of seawater through the sandy bottom to wells by the sea or mixing of fresh, inland water and infiltrated, saline seawater. Seawater wells are constructed as vertical or horizontal, depending on the heating and cooling requirements, i.e., the required amount of seawater. In addition to water intake by vertical and horizontal wells, water collectors laid on the seabed, through which a sand filter layer is deposited, are applied which then prevents the entry of biological micro and macro-organisms.

4 Conclusion

After the detailed analysis was carried out regarding the Blue Energy potential for the Italian and Croatian coasts, alongside the technology assessment following conclusions are derived:

- Blue Energy potential for wave and tidal energy is low in the north-eastern parts of the Adriatic Sea, with more potential in the other regions
- Technology readiness for Seawater Heat Pumps is at a satisfying level in all regions
- Thermal energy with the heat pump utilisation is showing the best perspective for exploitation
- There is a lack of similar projects for the Italian and Croatian coasts
- The procedure for obtaining required permissions is still unclear and complicated
- Funding and subsidies significantly affect the rate of installation of new devices as well as the payback period

Having all in mind, for further analysis both Seawater Heat Pumps and Wave Energy Converters are selected as the most prominent technology in selected regions. Therefore, in the second report of this analysis, they will be evaluated for several potential pilot locations, with the respective technical requirements and economic assessment.

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