Energy potential analysis of pilot areas

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Contents

List of Figures

List of Tables

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 for the pilot areas and pre-feasibility study of selected pilot locations analysis consists of two separate reports. In the previous report, seawater heat pumps and wave energy converters are selected as the most promising and appropriate technologies for the considered pilot areas. In this, in the second part of the report, potential pilot locations are selected, and prefeasibility studies are carried out. For the selected buildings, heating load and annual energy demand are calculated to evaluate the potential deployment of seawater heat pumps and make a comparison with conventional, used systems. For the wave energy converters, the production of electricity on the selected locations with rough investment costs is given.

1. Introduction

This report is made for project **"COASTENERGY - Blue Energy in ports and coastal urban areas"**, financed under Italy-Croatia CBC Programme, priority axis Blue innovation. This is a second report where potential pilot locations are selected, and prefeasibility studies are carried out. 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. The objective of this second report is to evaluate the potential of seawater heat pumps to replace the conventional heating and cooling systems and for the exploitation of wave energy.

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 utilization 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 was already mentioned, analysis is divided into two separate reports, in the first one, the BE potential is analysed for the predetermined area, and the most suitable technologies are selected. The second report will investigate the potential more in detail by estimating the potential for the most appropriate technologies 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).

2. Selection of pilot locations and technology applications

2.1 IRENA

2.1.1 Identification of feasible technologies and pilot areas

Estimation of the potential for the application of technologies for seawater thermal energy use is made for all public buildings, hotels and restaurants located no more than 100 m away from the coastline. Identified potential locations of public buildings are depicted in Figure 1, Figure 2, Figure 3, while hotels and restaurants are depicted in Figure 4 and Figure 5. Input parameters for potential estimation are based on the energy needs of the buildings found in EMIS and ECIS databases).

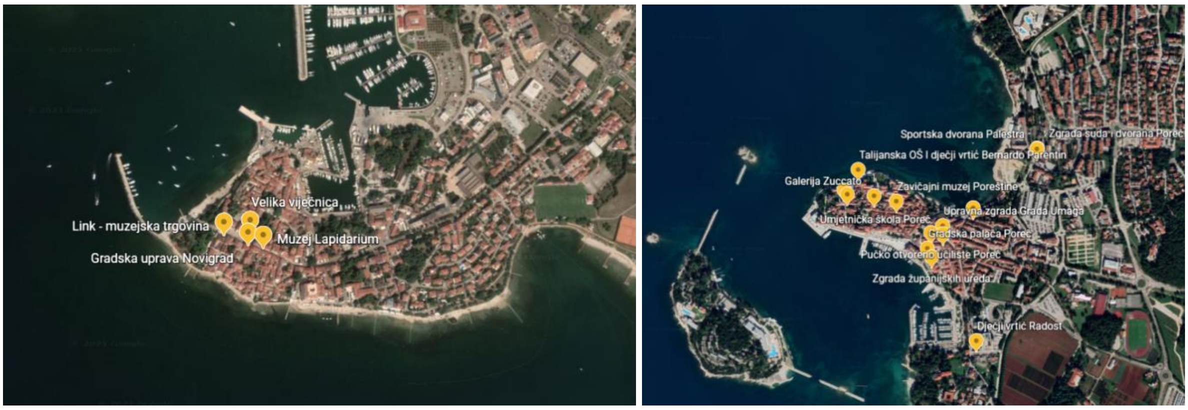

Figure 1 - Public buildings in Novigrad (left) and Poreč (right) - potential locations for application of SWHP

Figure 2 - Public buildings in Rovinj - potential locations for application of SWHP

Figure 3 - Public buildings in Umag (left) and Vrsar (right) - potential locations for application of SWHP

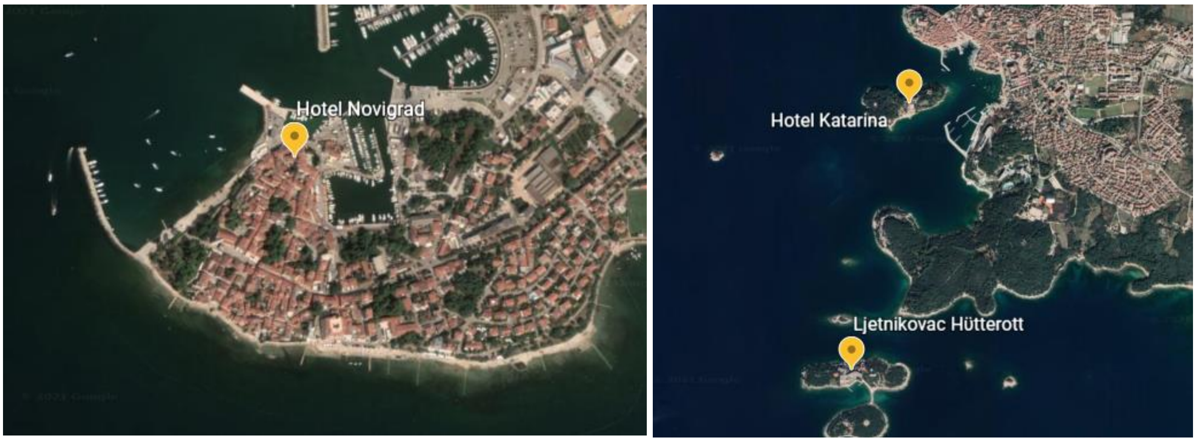

Figure 4 - Hotels and restaurants in Novigrad (left) and Rovinj (right) were identified as potential locations for the application of technologies for use of seawater thermal energy

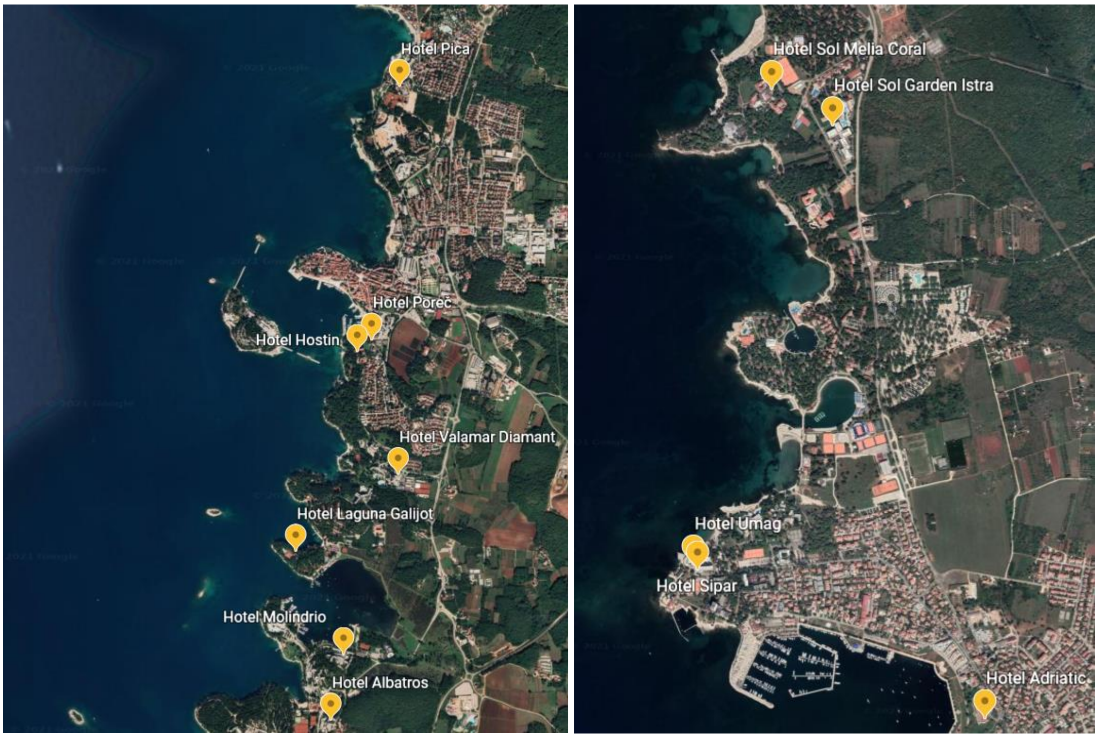

Figure 5 - Hotels and restaurants in Poreč (left) and Umag (right) were identified as potential locations for the application of technologies for use of seawater thermal energy

Following assumptions are made for potential estimation. Seawater intake is in depths between 5 and 10 m due to fact that coastal sea depth is below 10 m (up to a distance of 50 m from the coast). Due to shallow sea depths, subsurface seawater intake from wells by the sea is recommended. The temperature regime of the distribution system used in heating is 45/40 °C, the temperature regime of the distribution system used in cooling is 12/7 °C, while domestic hot water is heated up to 55 °C. The remaining parameters used for the estimation are given in Table 1 and

Specific heat capacity of seawater, c_w [kJ/(kg K)], and seawater density, ρ_w [kg/m^3], are temperature dependent. Thermal properties are defined for sea temperature of 11 °C in the heating season and 20 °C in the cooling season.

Table 2. Estimation of input parameters is based on commonly used parameters in installed systems or are based on field monitoring data for similar systems in operation.

Table 1 - Calculation parameters for estimation of the potential for the application of technologies for seawater thermal energy use in heating

Type of building	**Coefficient of performance for design conditions COP, [-]**	**Seasonal coefficient of performance SCOP, [-]**	**Seawater specific heat capacity c_w, [kJ/kg K]**	**Seawater density ρ_w, [kg/m^3]**	**A temperature difference of seawater in the heat exchanger $\Delta\vartheta_w$, [K]**	**Required specific heating capacity q, [W/m^2]**

1	Public use	4,4	4,2	4,003	1027	4	115
2	Hotel and restaurant						80

Specific heat capacity of seawater, c_w [kJ/(kg K)], and seawater density, ρ_w [kg/m^3], are temperature dependent. Thermal properties are defined for sea temperature of 11 °C in the heating season and 20 °C in the cooling season.

Table 2 - Calculation parameters for estimation of the potential for the application of technologies for seawater thermal energy use in cooling

Type of building		The energy efficiency ratio for design conditions EER, [-]	Seasonal energy efficiency ratio EER, [-]	Seawater specific heat capacity c_w, [kJ/kg K]	Seawater density ρ_w, [kg/m^3]	A temperature difference of seawater in the heat exchanger $\Delta\vartheta_w$, [K]	Required specific cooling capacity q, [W/m^2]
1	Public use	5,1	4,8	4,007	1025	4	70
2	Hotel and restaurant						70

Results of the estimation are presented separately for public buildings hotels and restaurants. Results include required electricity power capacity for installed heat pump, P_{el} [kW], the flow rate of seawater, q_v [m^3/h] and electric energy required to run the heat pump, E_{el} [kWh]. Coefficient of performance and energy efficiency ratio for design conditions are used to calculate the required seawater flowrate and required electric power for the installed heat pump. The seasonal coefficient of performance and seasonal energy efficiency ratio is used to calculate the required electricity for running the heat pump. Electric energy required to run the heat pump is calculated only for buildings found in the IEC database.

Buildings marked with an asterisk (*) do not have data for yearly heating energy needs to be expressed per m^2. In such a case, the average value of required yearly heating energy expressed per m^2 is used. Average value is 107,10 kWh/m^2.

Public buildings

Heating application

Table 3 - Estimation of potential for application of seawater heat pump for heating of public buildings

Building name	The total useful floor area of the building, [m^2]	Required heating capacity Φ_{gr}, [kW]	Required electricity power capacity for installed heat	Heat flux in evaporator Φ_{isp}, [kW]	Seawater flowrate q_v, [m^3/h]	Reference annual heat energy consumption $Q_{H,nd}$ [kWh/a]	Required electricity for running the heat pump, [kWh/a]

				pump P_{el}, [kW]				
ECIS database	Kindergarten and nursery Duga, Branch Department Bambi	555,65	63,90	14,52	49,38	10,81	28186,45	6711,06
	Administrative building of the City of Umag	561,37	64,56	14,67	49,89	10,92	77811,00	18526,43
	Umag City Hall	654,55	75,27	17,11	58,17	12,73	82553,00	19655,48
	Sport hall Umag	2505,00	288,08	65,47	222,60	48,73	972571,00	231564,52
	Preschool Kindergartens and nurseries Radost	692,10	79,59	18,09	61,50	13,46	90235,00	21484,52
	City Palace, Poreč	767,60	88,27	20,06	68,21	14,93	234253,00	55774,52
	Poreč City Library	218,00	25,07	5,70	19,37	4,24	34535,00	8222,62
	Poreč City Library - children's department	220,75	25,39	5,77	19,62	4,29	25637,00	6104,05
	Poreč Public Open University - phase A	1595,73	183,51	41,71	141,80	31,04	91876,55	21875,37
	Poreč Public Open University - phase B	450,00	51,75	11,76	39,99	8,75	18359,00	4371,19
	Poreč Art School	427,13	49,12	11,16	37,96	8,31	51682,00	12305,24
	City administration of Rovinj	1190,00	136,85	31,10	105,75	23,15	150339,00	35795,00
	Business space Rovinj	50,97	5,86	1,33	4,53	0,99	2630,23	626,25
	Homeland Museum of Rovinj	935,36	107,57	24,45	83,12	18,20	156662,00	37300,48
	* Preschool institution and kindergarten Radost 1	1139,75	131,07	29,79	101,28	22,17	122066,23	29063,39
	* Elementary school Vladimir Nazor Vrsar	2271,53	261,23	59,37	201,86	44,19	243278,89	57923,54
	Hospital for Orthopedics and Rehabilitation Prim. Dr. Martin Horvat							
	* Office building "L building" Rovinj	5706,96	656,30	149,16	507,14	111,02	611210,45	145526,30
	* Rovinj House of Culture	1238,22	142,40	32,36	110,03	24,09	132612,29	31574,35
EMIS	Novigrad City Administration	462,50	53,19	12,09	41,10	9,00	49533,35	11793,65
	LINK - Museum shop							
	Museum Lapidarium	391,04	44,97	10,22	34,75	7,61	41880,04	9971,44
	Grand City Hall Novigrad	250,13	28,76	6,54	22,23	4,87	26788,71	6378,26

	Bernardo Parentin Italian Elementary School and Kindergarten	1450,00	166,75	37,90	128,85	28,21	155293,74	36974,70
	Poreč County Office Building							
	Court building and Poreč hall							
	Zuccato Gallery							
	Romanesque house Poreč							
	Homeland Museum of Poreštine							
	Sport hall Palestra	500,00	57,50	13,07	44,43	9,73	53549,57	12749,90
	Komunalni servis Ltd Rovinj	600,00	69,00	15,68	53,32	11,67	64259,48	15299,88
	City Theater A. Gandusio Rovinj	692,00	79,58	18,09	61,49	13,46	74112,60	17645,86
	MMC, Rovinj	300,00	34,50	7,84	26,66	5,84	32129,74	7649,94
	Public Open University of Rovinj (yellow building)	1000,00	115,00	26,14	88,86	19,45	107099,13	25499,79
	Rubini Ltd Rovinj (business incubator)	80,00	9,20	2,09	7,11	1,56	8567,93	2039,98
TOTAL		**26906,34**	**3094,23**	**703,23**	**2391,00**	**523,44**	**3739712,37**	**890407,71**

Cooling application

Table 4 - Estimation of potential for application of seawater heat pump for cooling of public buildings

Building name		**The total useful floor area of the building, [m²]**	**Required cooling capacity Φ_{hl}, [kW]**	**Required electricity power capacity for installed heat pump P_{el}, [kW]**	**Heat flux in condenser Φ_{kon}, [kW]**	**Seawater flowrate q_v, [m³/h]**
ECIS database	Kindergarten and nursery Duga, Branch Department Bambi	555,65	38,90	7,63	46,52	10,17
	Administrative building of the City of Umag	561,37	39,30	7,71	47,00	10,28
	Umag City Hall	654,55	45,82	8,98	54,80	11,99
	Sport hall Umag	2505,00	175,35	34,38	209,73	45,87
	Preschool Kindergartens and nurseries Radost	692,10	48,45	9,50	57,95	12,67

	City Palace, Poreč	767,60	53,73	10,54	64,27	14,06
	Poreč City Library	218,00	15,26	2,99	18,25	3,99
	Poreč City Library - children's department	220,75	15,45	3,03	18,48	4,04
	Poreč Public Open University - phase A	1595,73	111,70	21,90	133,60	29,22
	Poreč Public Open University - phase B	450,00	31,50	6,18	37,68	8,24
	Poreč Art School	427,13	29,90	5,86	35,76	7,82
	City administration of Rovinj	1190,00	83,30	16,33	99,63	21,79
	Business space Rovinj	50,97	3,57	0,70	4,27	0,93
	Homeland Museum of Rovinj	935,36	65,48	12,84	78,31	17,13
	* Preschool institution and kindergarten Radost 1	1139,75	79,78	15,64	95,43	20,87
	* Elementary school Vladimir Nazor Vrsar	2271,53	159,01	31,18	190,18	41,59
	Hospital for Orthopedics and Rehabilitation Prim. Dr. Martin Horvat					
	* Office building "L building" Rovinj	5706,96	399,49	78,33	477,82	104,50
	* Rovinj House of Culture	1238,22	86,68	17,00	103,67	22,67
EMIS database	Novigrad City Administration	462,50	32,38	6,35	38,72	8,47
	LINK - Museum shop	-				
	Museum Lapidarium	391,04	27,37	5,37	32,74	7,16
	Grand City Hall Novigrad	250,13	17,51	3,43	20,94	4,58
	Bernardo Parentin Italian Elementary School and Kindergarten	1450,00	101,50	19,90	121,40	26,55
	Poreč County Office Building					
	Court building and Poreč hall					
	Zuccato Gallery					
	Romanesque house Poreč					
	Homeland Museum of Poreštine					
	Sport hall Palestra	500,00	35,00	6,86	41,86	9,16
	Komunalni servis Ltd Rovinj	600,00	42,00	8,24	50,24	10,99
	City Theater A. Gandusio Rovinj	692,00	48,44	9,50	57,94	12,67
	MMC, Rovinj	300,00	21,00	4,12	25,12	5,49
	Public Open University of Rovinj (yellow building)	1000,00	70,00	13,73	83,73	18,31

	Rubini Ltd Rovinj (business incubator)	80,00	5,60	1,10	6,70	1,46
	TOTAL	**26906,34**	**1883,44**	**369,30**	**2252,75**	**492,68**

2.1.2 Preliminary description of selected technologies and pilot areas

The pilot area of the COASTENERGY project was selected based on data from the EMIS and ECIS databases.

Within this chapter, only the following buildings are considered: buildings that currently use environmentally unacceptable fossil fuels (fuel oil, liquefied petroleum gas - LPG) as energy sources for space heating/domestic hot water preparation, buildings located relatively close to the sea at a distance <= 100 meters from the sea and buildings suitable for the installation of a seawater/water heat pump.

Proposed pilot area – based on EMIS database

The table below shows public buildings from the ISGE base at a distance of <= 100 m from the sea, which uses fuel oil as a fuel for space heating and is suitable for the installation of a seawater/water heat pump.

Figure 6 - Italian primary school and kindergarten Bernardo Parentin - a potential route for the supply of sea water

Table 5 - Western Istria - proposals for public buildings suitable for the installation of seawater/water heat pumps

City/ municipality	Name of the public building and address	The gross floor area of the building [m²]	Total useful floor area A_k [m²]	The current energy source for heating/DHW preparation	Energy consumption in 2019 [kWh/year]	Distance from the sea[1] [m]	Short description of the building (why it is appropriate)
POREČ	Italian primary school and kindergarten Bernardo Parentin	1.450,00	-	Fuel oil	59.526,75	35	The building is located along the coast, but it is recommended to carry out energy renovation of the building.
POREČ	City Palace, Obala Maršala Tita	–	767,60	Fuel oil	238.120,31	30	The building is located along the coast, but it is recommended to carry out energy renovation of the building.

Hotels

According to the Client's requirements, data on areas for hotels and restaurants located near the sea, which use fuel oil or liquefied petroleum gas (LPG) as energy sources for heating and DHW preparation, were collected from the ECIS database. The positions of these hotels are shown in the figure below, while all other information is shown in the table below.

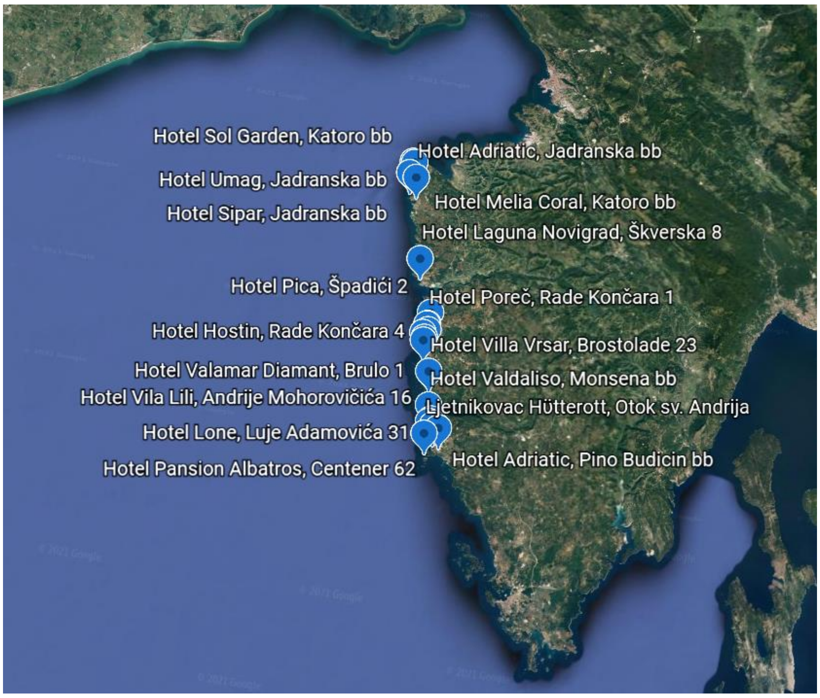

Figure 7 - Western Istria - hotels that use fuel oil and LPG as an energy source for heating and DHW preparation (source: ECIS database)

Table 6 - Western Istria - Hotels and restaurants near the coast

City/ Municipality	Hotel name	Address	The total useful floor area of the building [m²]	The energy source for heating/DHW preparation
NOVIGRAD	Hotel Laguna Novigrad	Škverska 8	2.626,34	fuel oil
POREČ	Hotel Valamar Diamant	Brulo 1	14.097,97	fuel oil
	Hotel Laguna Galijot	Plava Laguna 18	5.504,68	fuel oil
	Hotel Poreč	Rade Končara 1	2.970,94	fuel oil
	HOTEL HOSTIN	Rade Končara 4	3.279,40	LPG
	Hotel Pica	Špadići 2	18.750,00	fuel oil
	Hotel Albatros	Zelena Laguna bb	13.631,44	fuel oil
	Hotel Molindrio	Zelena laguna bb	10.395,09	fuel oil
	Hotel Molindro, Zelena laguna Centralni dio	Zelena Laguna bb	3.321,59	fuel oil
	Hotel Molindro, Zelena laguna Bloka D	Zelena Laguna bb	1.349,08	fuel oil
	Hotel Molindro, Zelena laguna Bloka G	Zelena Laguna bb	1.199,69	fuel oil
	Hotel Molindro, Zelena laguna Bloka A	Zelena Laguna bb	1.023,84	fuel oil
	Hotel Molindro, Zelena laguna Bloka F	Zelena Laguna bb	942,90	fuel oil
	Hotel Molindro, Zelena laguna Bloka E	Zelena Laguna bb	932,64	fuel oil
	Hotel Molindro, Zelena laguna Bloka C	Zelena Laguna bb	831,25	fuel oil
	Hotel Molindro, Zelena laguna Bloka B	Zelena Laguna bb	794,10	fuel oil
ROVINJ	Hotel Vila Lili	Andrije Mohorovičića 16	797,15	fuel oil

City/ Municipality	Hotel name	Address	The total useful floor area of the building [m²]	The energy source for heating/DHW preparation
	Hotel – Pansion Albatros	Centener 62	841,46	fuel oil
	Hotel Valdaliso - hotel	Monsena bb	5.845,00	fuel oil
	Hotel Valdaliso - restoran	Monsena bb	1.812,00	fuel oil
	Hotel Katarina Dvorac i depandansa 1	Otok Sv. Katarina	3.711,00	fuel oil
	Hotel Katarina Depandansa 2	Otok Sv. Katarina	2.440,00	fuel oil
	Ljetnikovac Hütterott	Otok sv. Andrija	1.644,20	fuel oil
UMAG	Hotel Sol Garden Istra	Katoro bb	17.677,80	fuel oil
	Hotel Sol Melia Coral	Katoro bb	15.453,16	fuel oil
	Hotel Umag	Jadranska bb	10.009,14	fuel oil
	Hotel Adriatic	Jadranska bb	9.153,50	fuel oil
	Hotel Sipar	Jadranska bb	7.077,21	fuel oil
VRSAR	Hotel - Villa Vrsar	Brostolade 23	577,13	LPG**

Other non-residential buildings

Other non-residential buildings at a distance of <= 100 m from the coast, which use fuel oil as the energy source for space heating, useful heated areas larger than 1,000 m² are shown in the figure and are listed in the table below.

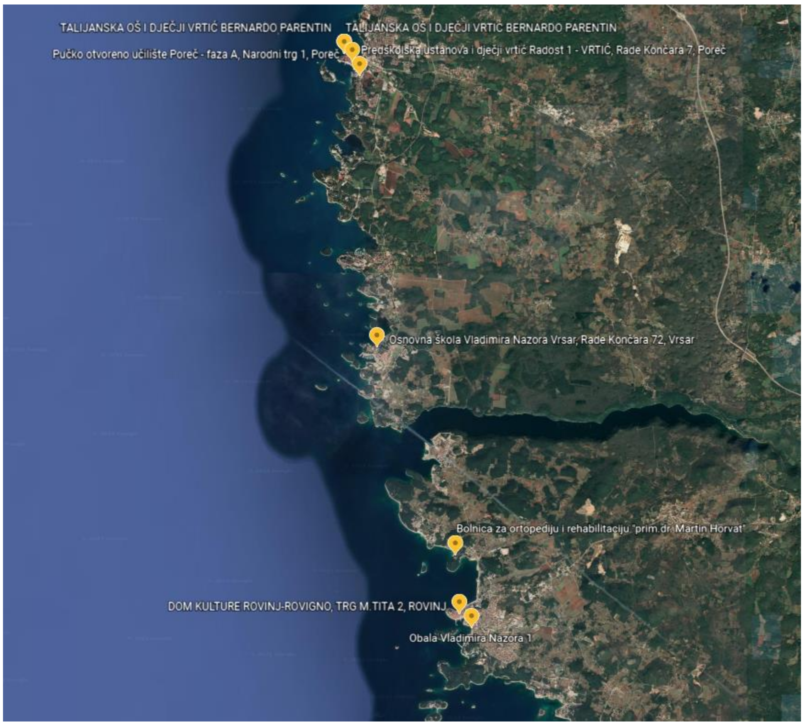

Figure 8 - Western Istria - other non-residential buildings that use fuel oil as an energy source for space heating (source: ECIS database)

Table 7 - Western Istria - other non-residential buildings near the coast (<= 100 m)

City/ Municipality	Type of non-residential building	Name of non-residential building	Address	The total useful floor area of the building [m²]	The energy source for heating/DHW preparation
Poreč	Education	Public Open University "Poreč" - phase A	Narodni trg 1	1.595,73	fuel oil
Poreč	Education	Preschool and kindergarten Radost 1	Rade Končara 7	1.139,75	fuel oil
Vrsar	Education	Primary school Vladimir Nazor, Vrsar	Rade Končara 72	2.271,53	fuel oil
ROVINJ	Hospital	Hospital for Orthopaedics and Rehabilitation Prim. Dr. Martin Horvat	Ulica L. Monti 2	-[2]	fuel oil
ROVINJ	Office	Office building "L building"	Obala Vladimira Nazora 1	5.706,96	fuel oil
ROVINJ	Office	HOUSE OF CULTURE ROVINJ - ROVIGNO	TRG M.TITA 2	1.238,22	fuel oil

Proposed buildings

Based on the analysis of buildings in the services sector using the EMIS database (Energy Management Information System) and ESIC database (Energy Certificate Information System), the following non-residential buildings are proposed as possible pilot areas:

Table 8 - Western Istria - proposed pilot locations

	City/ Municipality	Type of non-residential building	Name of non-residential building	Address	Year of construction	The total useful floor area of the building [m²]	The energy source for heating	The energy source for DHW preparation
1	Vrsar	Education	Primary school Vladimir Nazor	Rade Končara 72	1970	2.271,53	Fuel oil	Fuel oil
2	Poreč	Education	City Palace	Obala Maršala Tita 5	1908	767,60	Fuel oil	Electricity
3	Poreč	Education	Public Open University "Poreč" - phase A	Narodni trg 1	1885	1.595,73	Fuel oil	Electricity
4	Poreč	Education	Italian primary school and kindergarten Bernardo Parentin	Matka Laginje 6	–	approx. 1.250	Fuel oil	–

Figure 9 - Western Istria - pilot area - PROPOSAL 2 and PROPOSAL 3 - City Palace and Public Open University in Poreč

On March 1, 2021. a tour of the City Palace in POREČ; and Primary school Vladimir Nazor in Vrsar was made, after which the following building was selected for the pilot area of the COASTENERGY project:
City Palace, Obala Maršala Tita 5, POREČ

2.2 SDEWES Centre

2.2.1 Seawater heat pumps

The heat pumps are devices that can provide heating, cooling, and domestic hot water for residential, commercial, and industrial applications by moving thermal energy from a colder, low-temperature point, a heat source, to another point at a higher temperature, a heat sink. Since the heat is transferred in the opposite direction to the natural heat flow (from a high to a low temperature), additional mechanical work is required. Any heat pump installation can provide heating and cooling in parallel [1]. 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, fan coils or radiators) [2]. Figure 10 illustrates the heating and cooling mode of the deployed seawater heat pump.

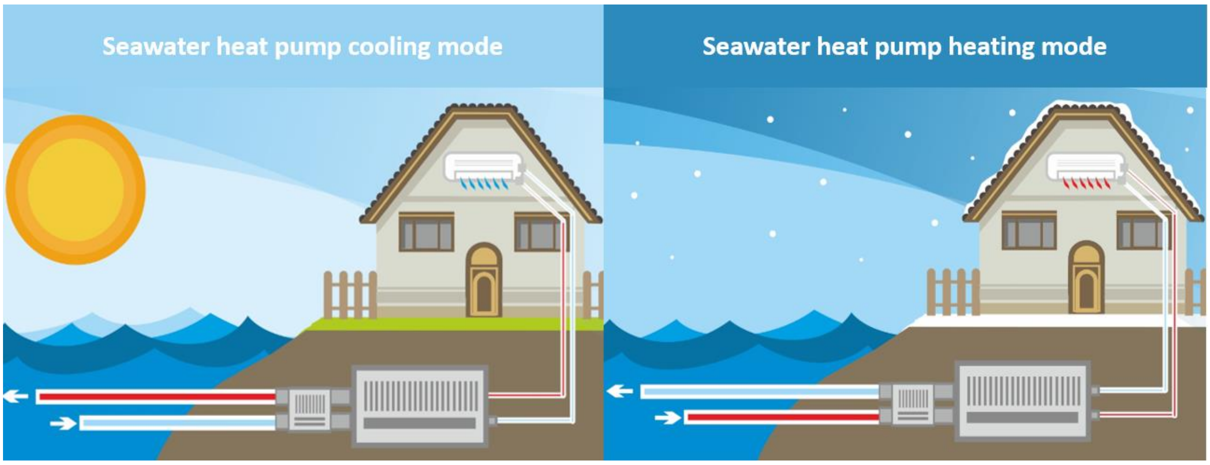

Figure 10 - Illustration of heating and cooling mode for seawater heat pumps [3]

2.2.2 Technical requirements

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. When designing the system parameters for the HVAC system and sanitary water preparation for seawater heat pumps following technical requirements should be fulfilled to maximise the system efficiency and achieve a faster return of investment:

- Thermal insulation of the house to minimise heat and cooling load and annual energy demand; additional refurbishment if needed
- Precise calculation of the heat and cooling load to select the appropriate nominal capacity of installed devices, as well as the precise calculation of daily hot water needs to select appropriate tank size and calculate additional heat demand for water heating
- Installation of heating and cooling distribution system applicable for low-temperature heating (55/45 °C) and cooling (30/35 °C) including fan coils, underfloor and ceiling heating devices and similar
- Installation of the unit by certified personnel, including the system balancing to maximise system efficiency and performance

Additionally, requirements which arise from the technology specifics are especially important when considering the installation of seawater heat pumps, because various permissions and construction work needs to be done [4]. One of the most important parameters which strongly influence the attractiveness of such a system is seawater intake. Such systems can be designed for direct and indirect water intake in the open or closed-loop [2]. For the former one, pipes are deployed directly on the seabed with elevated intake at the end. Distance from shore, in this case, is between a few meters up to 25 meters, depending on the sea characteristics. In the case of indirect water intake, brackish water with a high share of seawater is used. This is done by drilling the wells at the required depth where water characteristics are sufficient to ensure the continued operation of the installed system. Figure 11 presents the schematic view of potential water intake systems with the direct intake on the left and indirect intake through wells on the picture right.

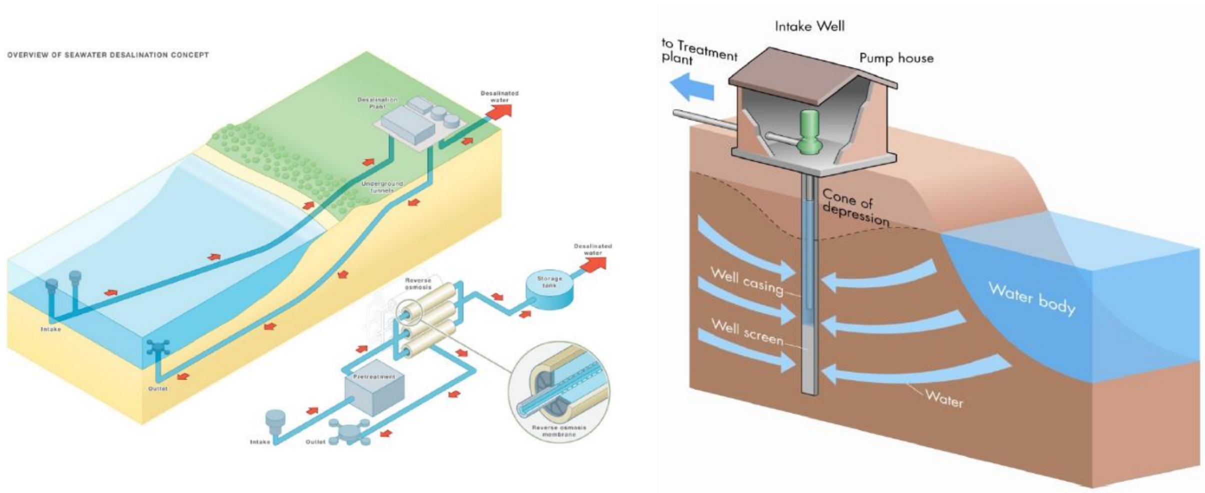

Figure 11 - Basic seawater heat pump system with direct water intake (left) and with the dwelling (right) [5]

As it can be seen in Figure 11 in the case of direct water intake, point sources of pipes need to be deployed with sufficient spacing between them to allow necessary mixing of seawater once when released from the system. This ensures the stable temperature of the intake point since there is no mixing between water released from the system and fresh intake. When it comes to the difference between open and closed-loop systems, for the case of sweater heat pumps, the open-loop system is occasionally preferred.

Figure 12 illustrates the combined open-closed looped system for the seawater heat pump for the case of the city of Trieste [6]. An open-loop system is used for seawater intake with an appropriate distance between hot and cold sources. The additional closed-loop system is used for the distribution of heating and cooling energy from heat pumps to potential consumers. This system presents the small version of the district heating and cooling system, strongly preferred in the future, and an ideal solution for decarbonisation of the heating and cooling sector. Furthermore, such a design might be interesting for application in mild climate conditions where the heating load is pronouncedly lower, implying a longer period for return of investment. Besides, such a system can also be used for the preparation of domestic hot water, which achieves additional savings in energy consumption. Finally, when the system is used for cooling as well, the investment can be returned in a shorter period since the working hours are greatly increased, allowing more considerable savings in energy demand due to high efficiency. Nevertheless, such systems require higher investment costs, and even more, complicated construction works. The bottom one is especially evident in the case of historical buildings or city centres.

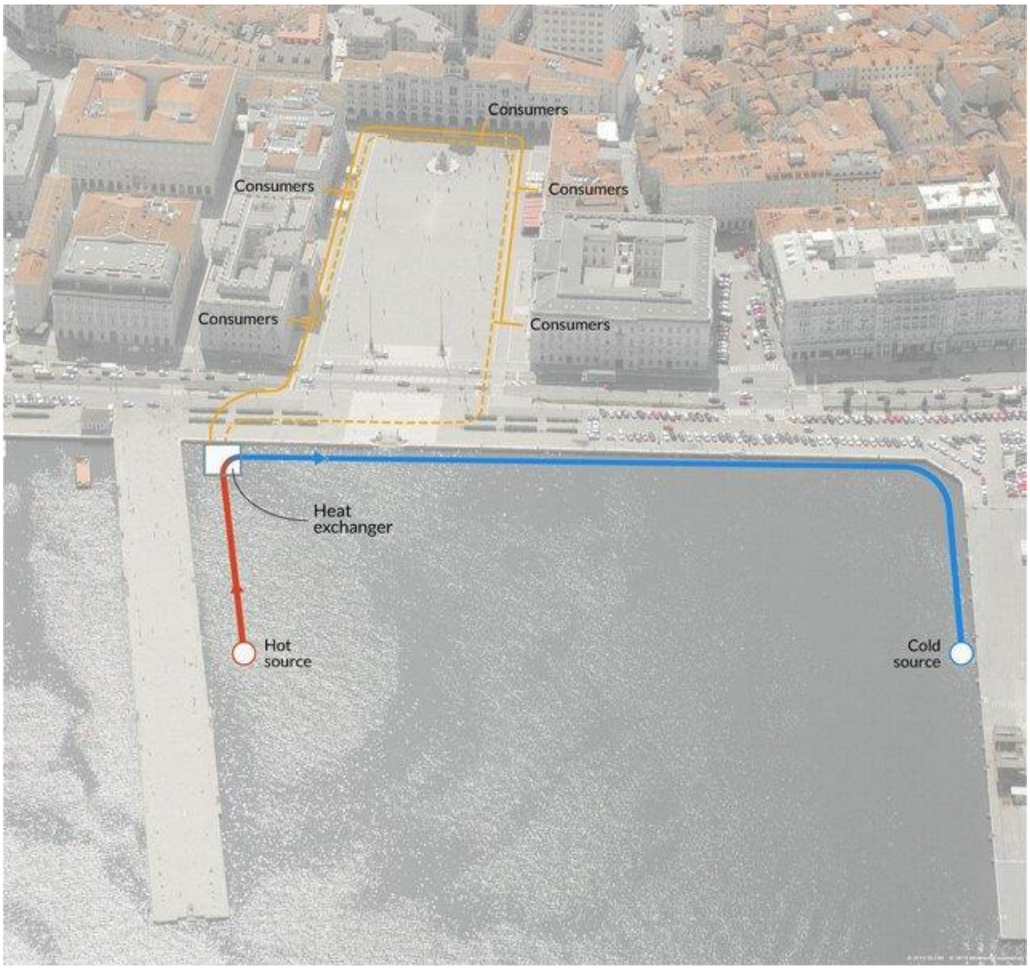

Figure 12 - Open-loop system for seawater heat pumps with the additional closed-loop distribution system [7]

Equipment needs

Pipes used for water intake are most often produced from high-density polyethylene (HDPE) with modular ending designed for easier clean-up. Since the pipes are placed at the seabed, various maritime species like shells and algae tend to block the intake hole and cause problems for system operation. In such a case, pipe endings can be easily taken-off and brought to shore for cleaning. This is also important to prevent potential contamination of the maritime environment by using various cleaning chemicals. Depth of intake strongly depends on the local characteristics and specifics. In general, the minimum required depth is around 5 meters, which ensures the uniform and constant temperature field is directly related to COP. Figure 13 shows the necessary interventions on land and sea for the deployment of pipes. Most often, besides the deployment of pipes, additional onshore works are required for the system itself. In the case of small systems, required onshore work does not represent significant investment costs and construction works, while for the case of a bigger system, a dedicated boiler room might be required as well.

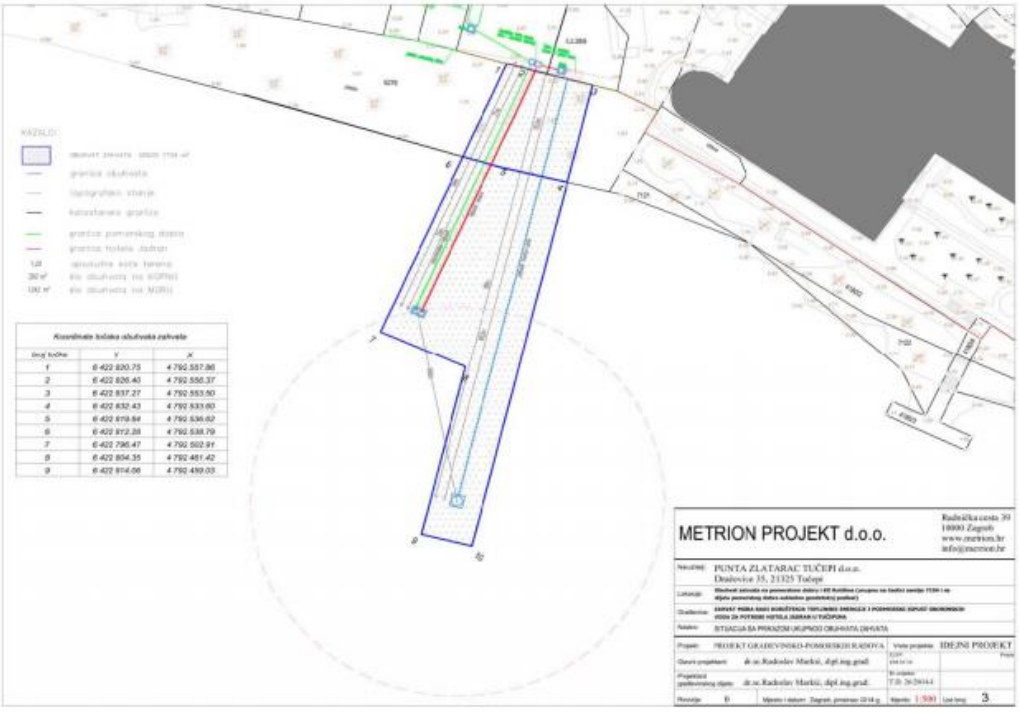

Figure 13 - Intervention of the planned project activities on land and sea [8]

2.2.3 Procedure for installation

The most challenging task for the installation of seawater heat pumps is to obtain all necessary permissions. Besides inevitable project documentation, additional environmental impact studies, various additional permission related to the usage of maritime goods are required as well. This includes concession for the intake and usage of seawater, a concession for the usage of maritime and onshore area and similar [9].

In the case of Croatia, direct usage of seawater as a working media for heat pumps is often prohibited or complicated. Therefore, it requires alternative solutions. One is the drilling of dwellings close to the utilization 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. Up to now, projects related to the exploitation of BE sources are seldom, implying that the procedure for obtaining all necessary permission is quite unclear. This is especially evident 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.

Following permissions are required for deployment of seawater heat pumps:

- Project and installation inclusion in spatial and maritime domain planning
- Concession for the usage of onshore land

- Concession for the usage of maritime domain for the deployment of intake/outtake pipes and the usage of seawater
- Concession and agreement with the relevant national body (Hrvatske vode) for the usage of inland water goods in case wells are used for water intake

The basic "roadmap" which needs to be followed to obtain all necessary permissions, is widely missing. In the first step, project documentation is prepared, and based on this, relevant public bodies are issuing an operational license, which proves the feasibility of the project. Moreover, the investor needs to obtain the concession for the usage of the maritime domain and seawater and request the inclusion of project installation in spatial and maritime plans. Simultaneously, the investor needs to contact the Harbour Master's office to prove that the installation does not interfere with the shipping.

Since the issuing concession might cause notable problems in project activities, and the end, it might not be issued; alternative routes are used for the deployment of technology. Most often this means drilling the wells for brackish water with a high share of seawater (up to 95%) is used as an energy source. Drilling requires additional investment costs for two reasons. Firstly, the potential of the selected location needs to be assessed, followed up by expensive drilling works. Also, Hrvatske vode d.o.o., as a relevant public body in the case of inland waters, needs to be contacted to negotiate the price for the usage of water.

The procedure for obtaining the concession for the usage of maritime goods is partially defined by the *Law of maritime good and seaports* (N.N. 158/03, 141/06, 38/09, 123/11 - OiRUSRH, 56/16 i 98/19) (the Law in following lines) and by supplementary *Decree on the procedure for granting a concession approval on a maritime domain* (N.N. 36/04, 63/08, 133/13, 63/14) (the Decree in the following lines) available in Official Gazette. Even though the main obligations and steps are described well in the existing regulatory framework, problems arise when the implementation takes place. More precisely, as it was already mentioned, the issuing permits regarding the concession and usage of maritime gods are the most complex part due to the unclarity of who is in charge. To initiate the procedure for obtaining the concession for the usage of maritime goods, the following documents are needed:

- Project documentation with the technical data and requirements
- Location permit and inclusion of the concessionaire area in the land books; before this, the borders of the area which is about to be given in concession must be precisely determined

Once these two conditions are fulfilled, the investor can initiate the procedure for granting concession under the Law and Decree. In the following lines, the workflow Figure 14 for obtaining permission is described and in the end, we present potential solutions to ease the procedure.

1) According to the Law, Articles 6 and 7, two types of activity can be performed on maritime goods:
    - Commercial usage
    - Special-dedicated usage

In the case of the deployment of seawater heat pumps, a concession for special-dedicated usage should be asked. Article 17 defines that in such a case, a written request needs to be addressed to the Ministry of the sea, transport and infrastructure which is a responsible public authority.

2) According to the same Law, Article 19, there are two types of objects which can be built for special-dedicated usage:

- Construction of buildings for religious purposes on the maritime domain, carrying out activities in the field of culture, social welfare, education and science, informing, sport, health, humanitarian, and other activities not performed to gain profit
- Building (on the maritime domain) buildings and other infrastructure facilities (roads, railways, water supply, sewage, power grid, a telephone network, etc.) for the needs of defence, internal affairs, regulation of rivers and other similar infrastructure facilities

Once again in the case of seawater heat pumps, the second option is the appropriate one since it includes energy infrastructure.

3) According to Article 20 of the same Law, the responsible public authority for granting concession is:
    - The Republic of Croatia (through Ministry), or
    - County administration (through County Council), or
    - Municipality (local) administration (through Municipality Council)

This third step is the most complicated one and often results in project delay since it is not clear which public body of this three presented should be in charge. This is also important since each public authority can give concession with different periods of duration (between 5 and 99 years). Since the Ministry is often not very well informed about the local needs and specifics, it would be reasonable to give local and regional authorities rights to grant the concession for such small-scale project which involves households or even bigger complex like hotels, sports hall or similar. The system size in these cases varies between a few kilowatts to several megawatts. Besides, Article 21, says that the county council on the proposal of the county prefect can give the rights to local municipality councils to issue the concessions in cases when projects are of great relevance for the local municipality. This would significantly enhance, and even more, encourage the development of such projects and the total number of installed devices.

4) Signing the Concession contract

Once when all requirements are fulfilled, the two sides are signing the contract with the defined borders of maritime good, duration of the concession, annual fee and other general rules which must be respected.

Additional demands described in Law:

- Article 10, Republic of Croatia is a governing body for maritime spatial planning (directly or indirectly through regional/local public authorities)
- Article 13, the concession fee is equally divided between the national, regional, and local public authority
- Article 27, for all disputes, the Ministry is a relevant public authority
- Article 28, the concession fee is symbolic or in case of commercial project mutually arranged
- Article 50, Harbour Master’s Office oversees the supervision of the usage of maritime goods

Additional requirements described in Decree:

- Article 24, defines the relevance of public authorities for considered projects, and the maximum period of concession duration

- Article 25, defines that written request is required when seeking concession:
    - Name, surname, residence place; or full data for legal entity
    - Conceptual design and declaration of the intended use of the maritime goods
    - A statement of the competent authority for spatial planning on the significance of the considered object for which specific use is sought; and opinion on the compatibility of the conceptual solution with the spatial documentation;
    - Proof of registration if the applicant is not a natural person
- Article 26, defines in which form the request should be addressed
- Article 27, when the request for a concession is received, compliance check with the spatial plan must be done in 30 days, and based on this proposition for the concession is made
- Article 28, Harbour Master's Office must give permission and agreement regarding the shipping safeness and compliance with maritime spatial plans
- Article 39, the concession fee is dived into two parts (fixed one - based on occupied m^2, variable – depending on the purpose of usage)

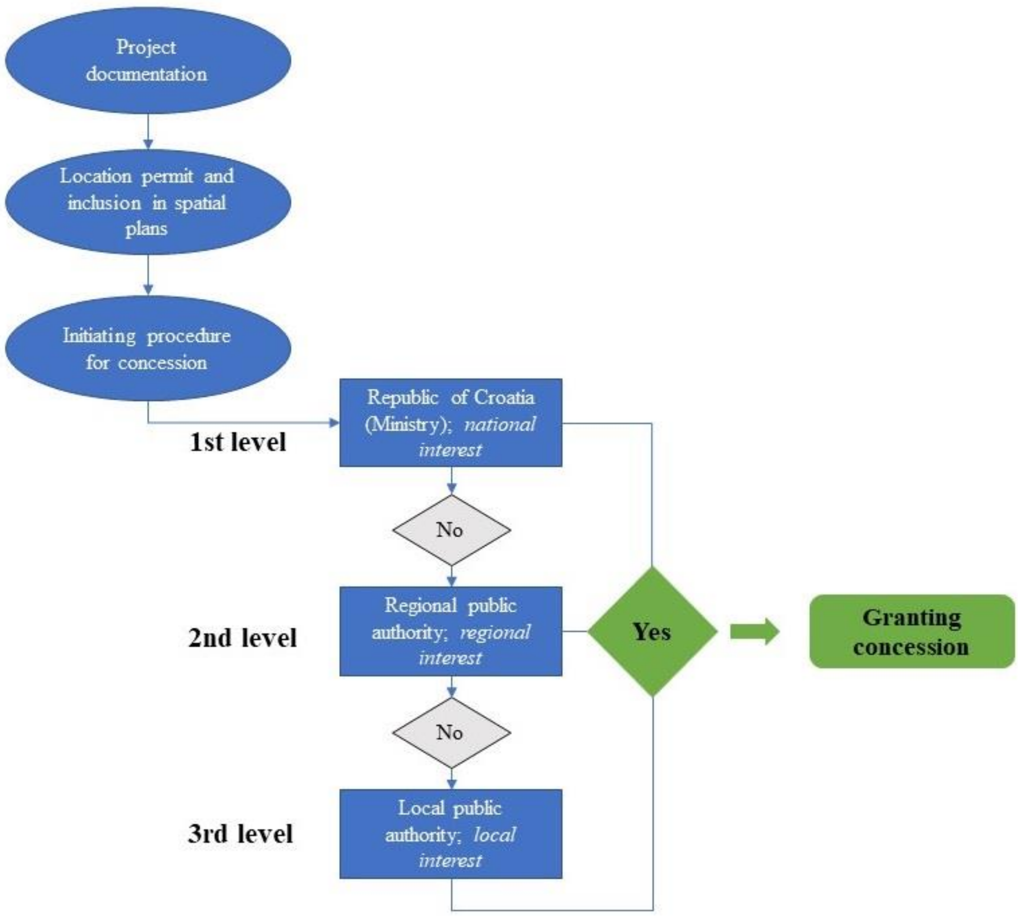

Figure 14 - Flowchart of required actions when asking for a concession

2.2.4 Pilot area analysis

According to the data from the 2011 Census, 10 995 people were living on the Cres-Lošinj archipelago at that time. This data indicates a trend of depopulation of the island compared to previous decades. The Cres-Lošinj archipelago administratively belongs to two local self-government units: The City of Cres and the City of Mali Lošinj [10].

Geography and climate conditions

The Cres-Lošinj archipelago is located on the north of the Adriatic Sea, and it consists of three major islands: Cres, Mali Lošinj and Veli Lošinj mutually connected by the roads and bridges and connected to the mainland by several ferry lines (Figure 15). Spatially, it is the largest archipelago in the Adriatic, with a total of 34 islands, islets and reefs located around the islands of Cres and the island of Lošinj. The total area of the archipelago is 509.39 km². Besides, six more inhabited islands are located alongside the west and south coast of the island of Lošinj: Unije, Ilovik, Susak, Srakane Male, Srakane Vele and Sv. Peter. Due to the extremely high biological diversity and its valuable biological heritage, the entire area of the Cres-Lošinj archipelago is included in the ecological network Natura 2000. The tourism sector, which is the most important economic branch, areas as "eco" destinations, but also by introducing several environmental standards in their business. In this context, the energy transition is becoming an increasing priority in the political agenda of cities and counties.

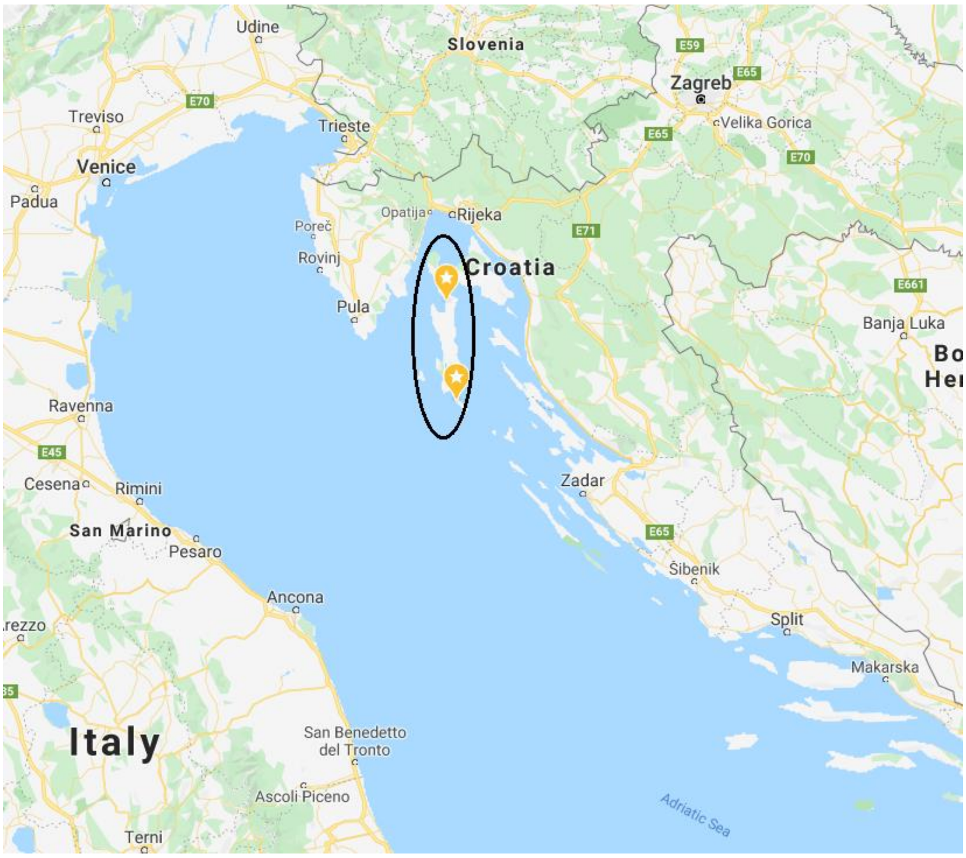

Figure 15 - Location of the archipelago

Climate can be considered the Mediterranean with a continental influence. The mean annual temperature is around 16.3 °C for the Mali Lošinj and around 14.5 °C for Cres. The sea cools the islands in the summertime and warms them in winter, ensuring pleasant temperatures. During the average summer, the average temperature is slightly above 25 °C, while the lowest average temperature remains above 0 °C during the winter periods. As it can be seen from Figure 16, the maximum monthly average temperatures are the same for both biggest settlements on the island, while the slightly lower minimum temperatures are noticed for Cres [10].

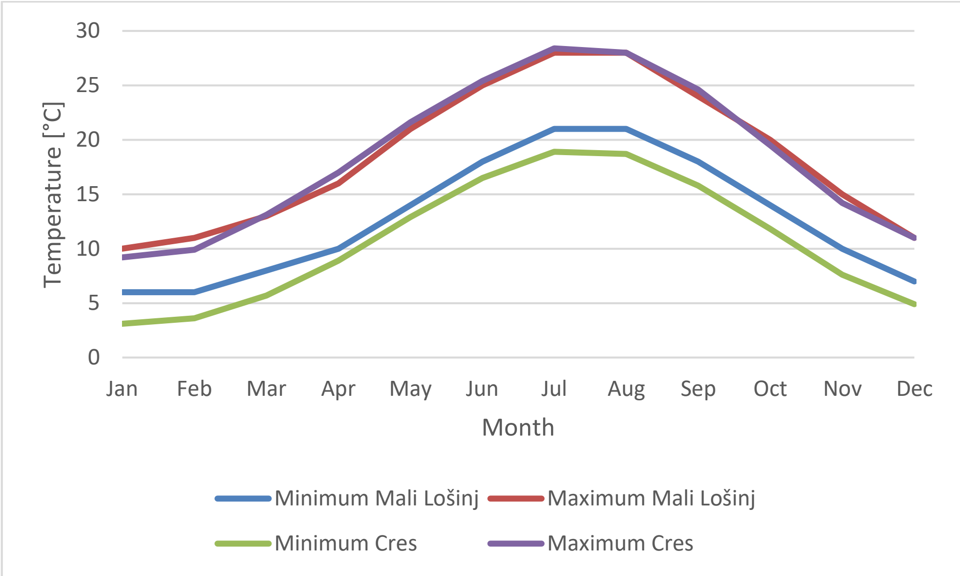

Figure 16 - Average monthly temperatures for Cres and Mali Lošinj [11]

The average seawater temperature for the Adriatic Sea is between 11 and 24 °C during the year. Figure 17 and Figure 18, present the average sea temperature for the Cres and Mali Lošinj, which varies between 11 and 26 °C during the year. At the depths where often, seawater is fetched (>5m) the average temperature is up to 14 °C during the year.

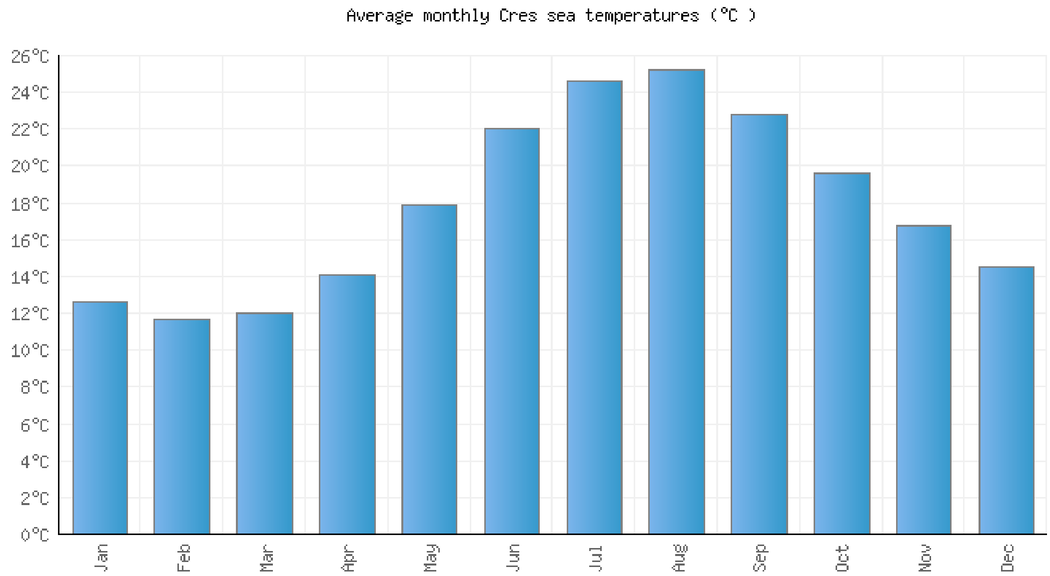

Figure 17 - Average monthly sea temperatures for Cres [12]

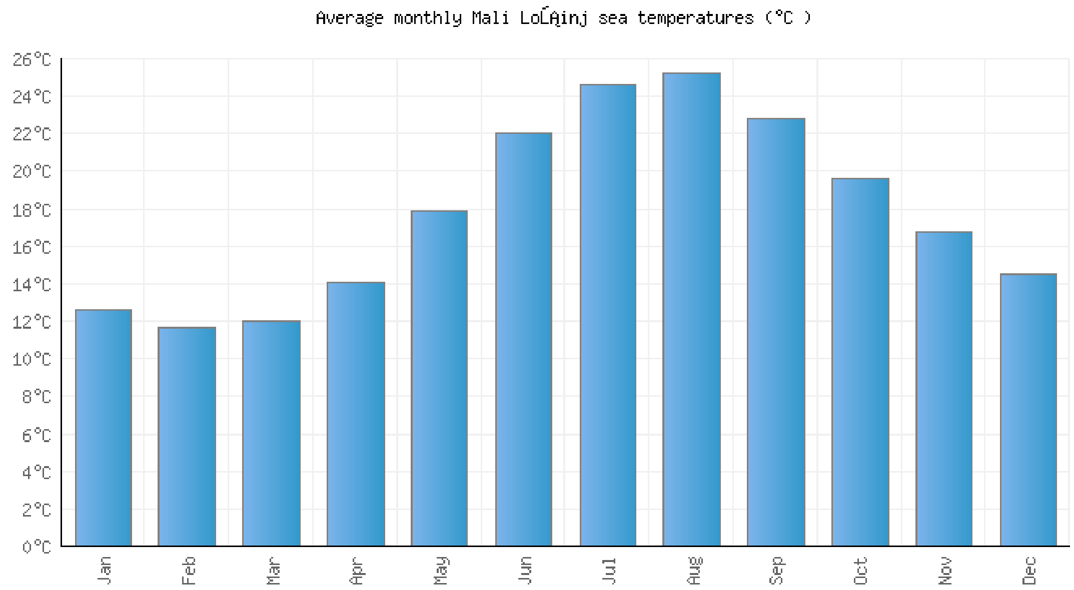

Figure 18 - Average monthly sea temperatures for Mali Lošinj [13]

The energy demand for Public buildings

Energy demand analysis of public buildings was done for *"Transition Plan of for Clean Energy Islands"*, coordinated by local development agency *"Otočna razvojna agencija (OTRA) "* [10]. In this report, the analysis was done for each building by the type of used fuels and their respective energy consumption. Electricity is a primary form of energy consumption for different purposes, including spatial heating and cooling. Besides, heating oil, liquefied petroleum gas (LPG) and biomass pellets are used to satisfy heating demand. This includes residential spatial heating and preparation of domestic hot water. Especially interesting is to analyse the consumption of fossil fuels like heating oil and LPG. Both fuels are mostly used for heating needs; therefore, they could be effectively substituted with seawater heat pumps. Table 9 shows the heating oil consumption in public buildings for 2018. Altogether, in Cres and Mali Lošinj, seven buildings are using heating oil to satisfy heating needs. In total, around 42 000 litres of heating oil are used, accounting for about 500 MWh in terms of energy consumption. In terms of CO_2 emissions, more than 134 00 tonnes are released from oil boilers, and this could be effectively mitigated by the deployment of seawater heat pumps. Since the electricity mix in Croatia is not 100% renewable, this savings would be lower due to CO_2 emissions from the power sector.

Table 9 - Heating oil consumption 2018

	Building	Heating oil (l)	Final energy consumption (kWh)	CO_2 emissions (t)
1.	OŠ Frane Petrića – Cres	11.205	132.891,3	35,482
2.	Lječilište – Veli Lošinj	3.140	37.240,4	9.943

3.	Odgojni dom – Mali Lošinj	2.415	28.641,9	7.647
4.	Srednja škola – Mali Lošinj	2.450	29.057	7.758
5.	Srednja škola – Cres	1.230	14.587,8	3.895
6.	Upravna zgrada Grad Mali Lošinj	4.300	50.998	13.616
7.	Školska dvorana – Mali Lošinj	17.680	209.684,8	55.986
	Total	**42.420**	**503.101,2**	**134,327**

Energy coefficient 11,86 kWh/l   Emission factor 0,267 kg CO2/kWh

Table 10 presents the consumption of LPG. Around 25 275 kg of LPG is used annually, ensuring around 323 MWh of energy, and contributing to around 73 000 tonnes of CO_2 emissions.

Table 10 - Liquified petroleum gas consumption in 2018

	Building	LPG (kg)	Final energy consumption (kWh)	CO_2 emissions (t)
1.	Lječilište – Veli Lošinj	5.780	73.984	16.794
2.	Odgojni dom – Mali Lošinj	7.115	91.072	20.673
3.	Odgojni dom – Cres	12.380	158.464	35,971
	Total	**25.275**	**323.520**	**73,439**[3]

Finally, most buildings are using electricity to satisfy heating needs. Table 11 shows the total electricity consumption in public buildings. Most of the buildings have some form of heat pumps units such as split systems used both for heating and cooling. Since these devices already have high COP, the potential for deployment of seawater heat pumps in these cases is significantly lower.

Table 11 - Electricity consumption in 2018

	Building	Electric consumption (kWh)	CO_2 emissions (t)
1.	Creski muzej	22.824	3,606

[3] *Energy coefficient 12,8 kWh/kg   Emission factor 0,227 kg CO2/kWh*

2.	DV Girice – Cres	58.657	9,268
3.	Gradska knjižnica – Cres	12.023	1,900
4.	Gradska uprava – Cres	106.142	16,770
5.	OŠ Frane Petrića – Cres	56.846	8,982
6.	Dom za starije – Mali Lošinj	107.264	16,948
7.	Dom za starije – Cres	43.571	6,884
8.	OŠ Maria Martinolića – Mali Lošinj	156.823	24,778
9.	Dom zdravlja – Mali Lošinj	114.346	18,067
10.	Lječilište – Veli Lošinj	352.486	55,693
11.	Odgojni dom – Mali Lošinj	102.516	16,198
12.	Odgojni dom – podružnica Cres	76.990	12,164
13.	Srednja škola – Mali Lošinj	54.798	8,658
14.	Srednja škola – Cres	19.283	3,047
15.	Lošinj usluge	17.783	2,810
16.	DV Mali Lošinj (centralni i villa perla)	103.445	16,344
17.	DV Veli Lošinj	40.714	6,433
18.	DV Nerezine	11.109	1,755
19.	Upravna zgrada Grad Mali Lošinj	101.841	16,091
20.	Školska dvorana – Mali Lošinj	33.455	5,286
	Total	**1.592.916**	**251,681**[4]

[4] *Energy coefficient 12,8 kWh/kg   Emission factor 0,227 kg CO2/kWh*

Building refurbishment to increase energy efficiency is carried out only on four buildings, of which all except DV Girice are using heating oil.

- DV Girice – Cres (2015.)
- Lječilište – Veli Lošinj (2018.) partially
- OŠ Frane Petrića – Cres (2019.)
- Srednja Škola – Cres (2019.)

Energy demand in the residential sector

Energy demand in the residential sector was analysed by conducting surveys among residents. Table 12 summarises gathered results, alongside the covered heating area and specific consumption. The dominant heating sources are electricity and wood with a combined share of 88%, while the rest is covered by pellets and heating oil. Since heat pumps already represent a high share of heating sources, and due to low heat demand, the potential for deployment of seawater heat pumps can be neglected, at least in terms of return of investment.

Table 12 - Residential heating demand and energy sources

Fuel	Share in total consumption (%)	Heating area (m^2)	Specific consumption (kWh/m^2)	Energy demand (kWh)	CO_2 emissions (t)
Electricity	39,73	105.876,48	101,72	10.769.755,24	1.701,621
Wood	48,40	128.981,16	245,7	31.690.671,01	0
Pellets	6,69	17.828,18	90,8	1.618.798,84	0
Heating oil	5,18	13.804,18	145,76	2.012.649,74	537,378
Total	**100**	**266.490,00**	**146,00**	**46.091.874,82**	**2.238,999**

2.2.5 Selection of pilot locations

Energy transition for the archipelago consists of five pillars: electricity production, heating and cooling, road and maritime transport and horizontal policies. The second pillar related to heating and cooling demand is the most interesting for this study, and it is divided into four strategies. The second strategy is directly related to the replacement of oil boilers and heating oil with renewable energy systems. Considered alternative fuels to replace currently used fossil fuels are pellets and wood biomass. Nevertheless, the fourth strategy directly promotes the usage of thermal potential of the Adriatic Sea, estimated to be around 1 kW/m^2h. As the first step for potential evaluation, buildings with at least partially publicly available data are considered. Figure 19 shows the location of all considered buildings on the islands. As can be seen, most of the buildings are located either in the town of Cres or Mali Lošinj. Altogether more than 30 buildings are analysed, with a focus on those which are using fossil fuels as the primary energy source for spatial heating and hot water preparation.

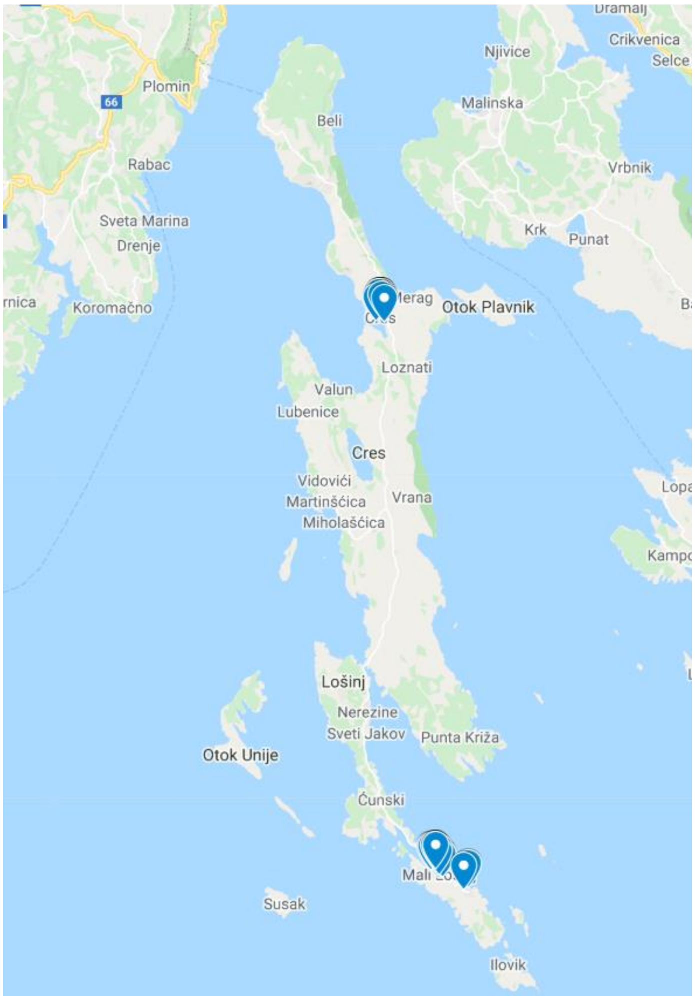

Figure 19 - Location of analysed buildings

Buildings proposed as a potential pilot location for deployment of seawater heat pumps are following, and their location is marked in Figure 20:

- OŠ Frane Petrića – Cres
- Odgojni dom – Mali Lošinj
- Dom za starije osobe Marko A. Stuparić-Cres

Data regarding the installed heating capacities and annual energy demand are obtained from the Information system for energy management (hrv. ISGE – Informacijski sustav za gospodarenje energijom).

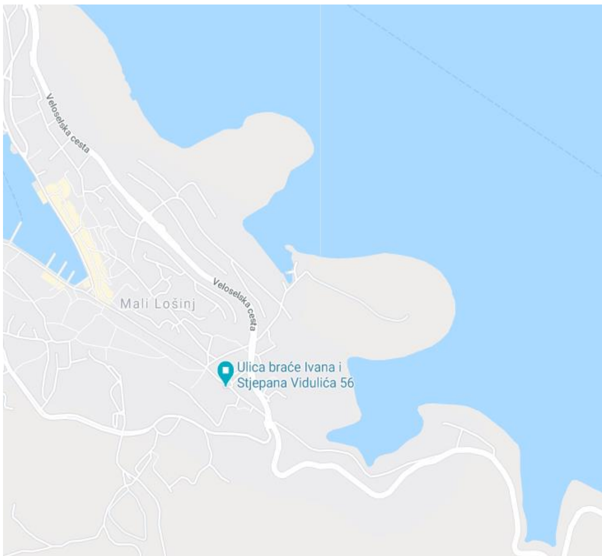

Figure 20 - Location and addresses of selected buildings

OŠ Frane Petrića – Cres

This object is an elementary school, recently refurbished to improve energy efficiency. Nevertheless, heating oil remained as the primary heating source, both for spatial heating and hot water preparation. The object is used five days a week for 13 hours from September until June by approximately 250 users, mostly pupils and school staff. Heating demand is satisfied by two oil boilers of an installed capacity of 920 kW. The last available data were for 2019 when 19 397 litres of heating oil was used, providing more than 177 000 kWh of energy. In the ISGE system, it was found that a useful area is around 5 990 m^2 and heating volume slightly above 24 000 m^3. Figure 21 presents the annual heating oil consumption in litres and produced heat in 2019. During the summer period, the system is only used for heat water preparation with a pronouncedly lower load than the rest of the year [14].

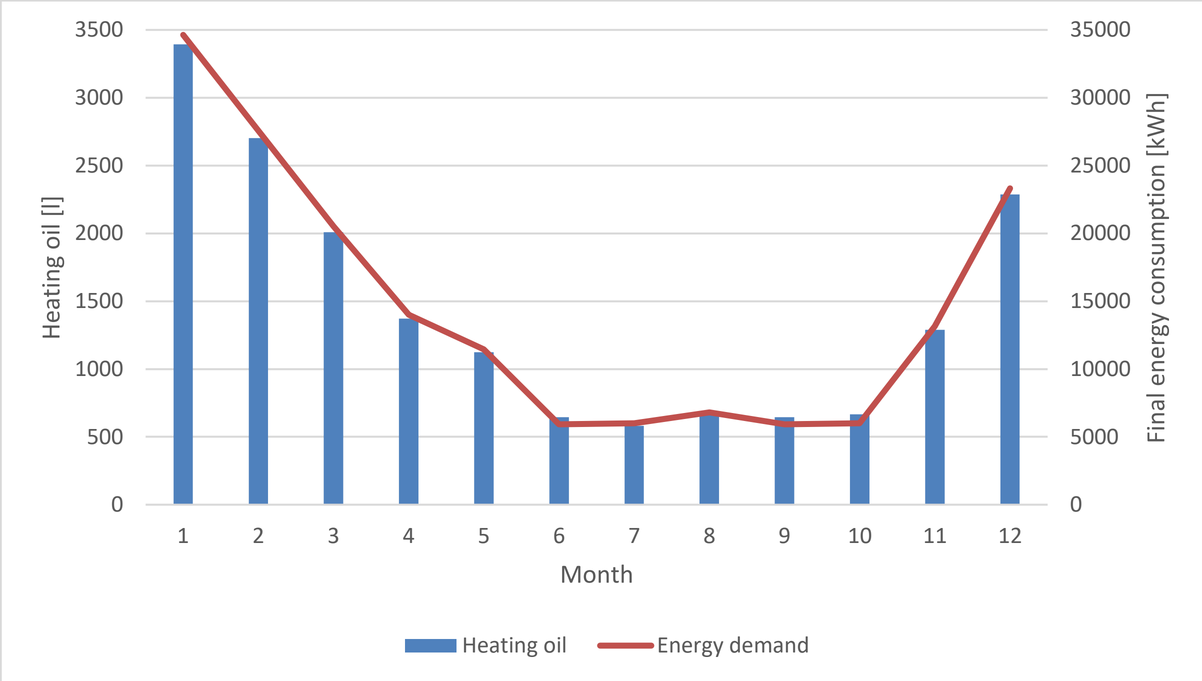

Figure 21 - Heating oil consumption and providing energy in 2019 - OŠ Frane Petrića – Cres

Odgojni dom – Mali Lošinj

This object consists of two buildings of which one is a small sports hall, and the other one is a pupil's dormitory. The object is built at the begging of the 20th century by the combination of bricks and stones, without thermal insulation. Windows are made of wood with one glazing. As a heating source for both spatial heating and hot water preparation, liquified petroleum gas is used. The installed boiler has a capacity of 200 kW and annual consumption of approximately 10 500 kg of LPG, providing 144 200 kWh of heating energy for the dormitory and sports hall. It should be emphasized that the last available data regarding consumption are from 2010 [14]. Figure 22 illustrates the data about the consumption and energy demand in 2010. As can be seen, notable consumption is observed during the winter period. Lower consumption for November and December is probably due to accounting and payment mechanisms, but the overall consumption on an annual basis remained unchanged for previous years; therefore, total demand could be estimated with such values.

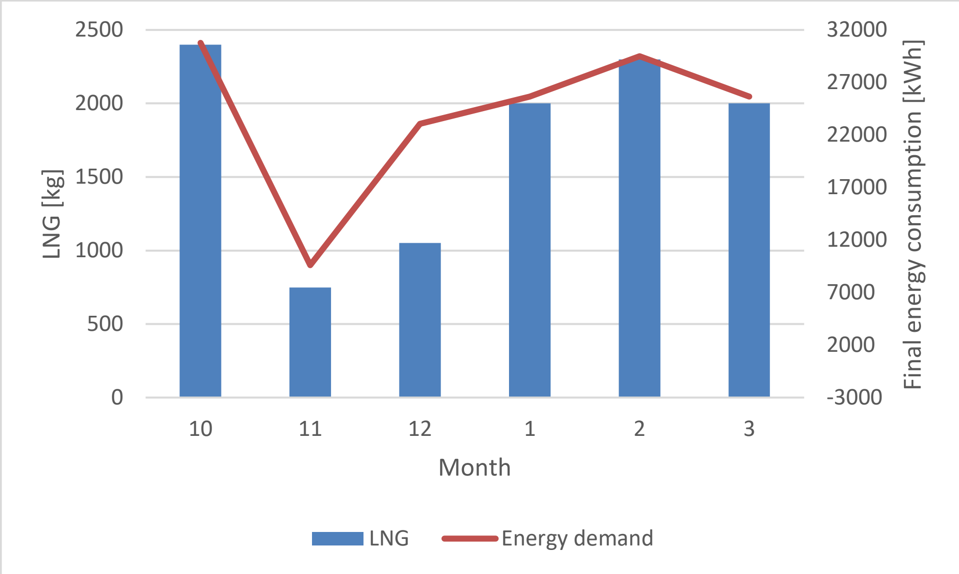

Figure 22 - LPG consumption and provided energy in 2010 - Odgojni dom – Mali Lošinj

Regarding the construction parameters, the dormitory has around 877 m^2 of useful surface on 5 floors and radiators of installed 130.2 kW capacity. It is used 7 days a week by 40 consumers. The sports hall has a small useful area of 100 m^2 heated by fan coils of installed capacity slightly above 28.5 kW [14].

Dom za starije osobe Marko A. Stuparić-Cres

This building is a retirement home located next to the sea, which marks it as a perfect location for seawater heat pumps. Besides, the building seeks for refurbishment to increase energy efficiency. Currently, LPG is used to satisfy heating demand with average consumption in the last five years of 15 038 kg, providing 166 936 kWh of energy. The average value is calculated for the last five years since the variation are visible in this period (Figure 23).

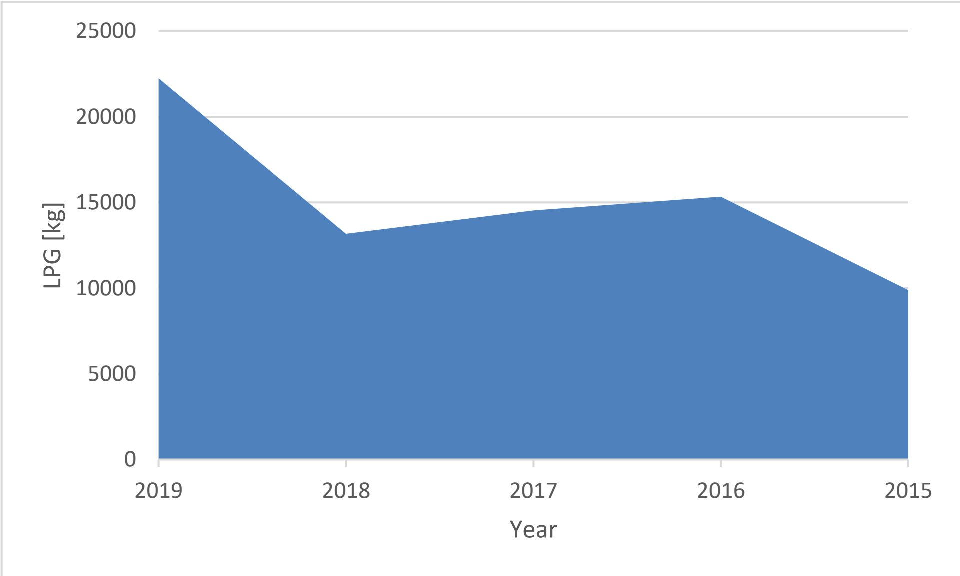

Figure 23 - Average LPG consumption in the last five years for Dom za starije osobe Marko A. Stuparić

The building has a useful heating area of 470 m^2, with a constant number of 20 users 7 days a week for a whole day. Specific annual energy consumption of 355.2 kWh/m^2. Even though the object of this type is expected to have slightly higher energy consumption, this is a huge value, which indicates that renovation is necessary. Also, for this building, an on-site visit is strongly recommended due to obtaining high values regarding energy demand, but also to additionally investigate the location potential since it is next to the sea.

2.3 DURA

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, seawater would be deprived of thermal energy and then transported for energy to the building heating system. 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 analyse 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.

2.3.1 Analysis of natural conditions

Analysis of natural conditions in the Dubrovnik area such as bathymetric data and sea temperature analysis; the analysis of natural conditions is done to determine the technical and economic potential and justification of investing in technologies that use blue energy with special emphasis on the use of marine thermal energy.

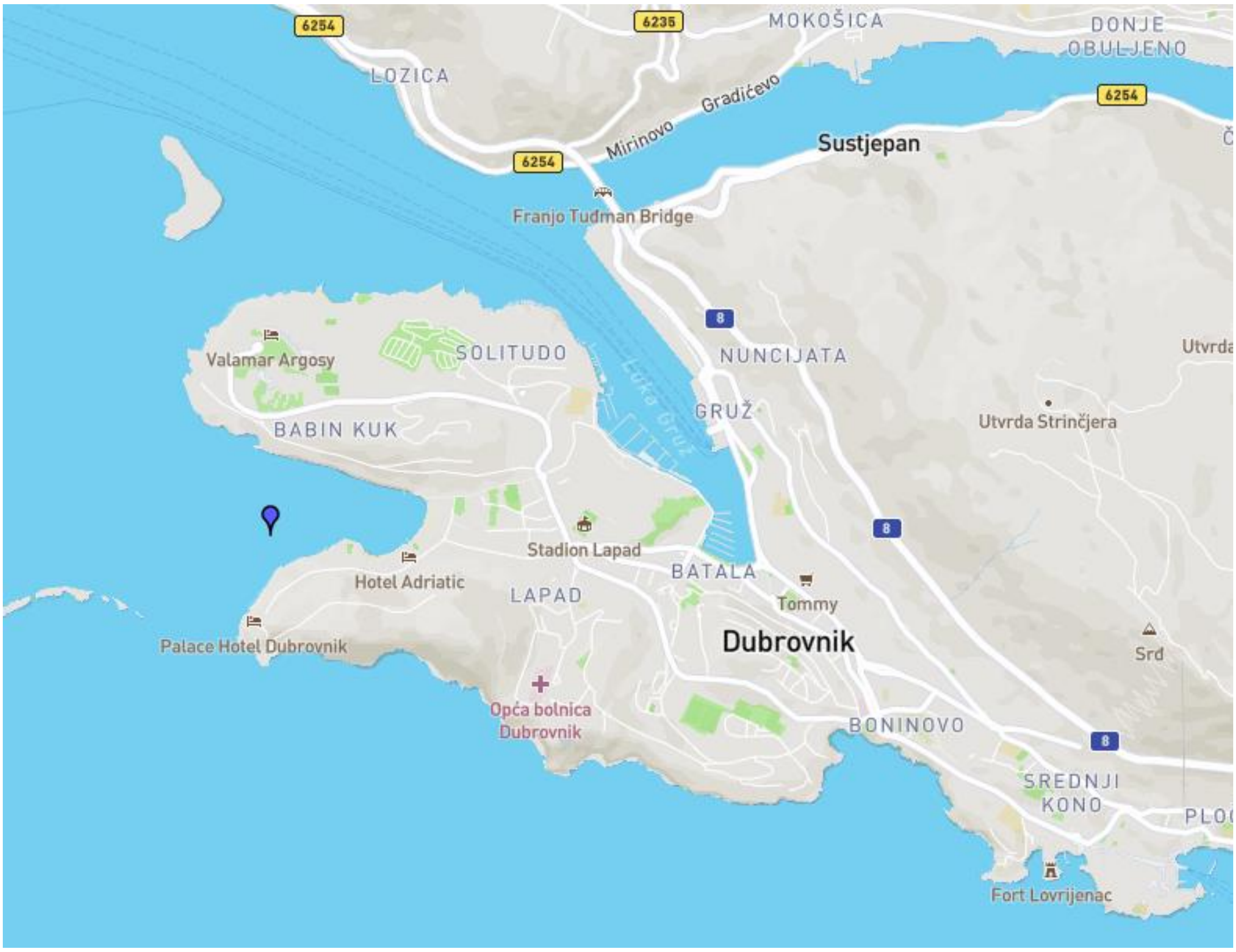

Figure 24 - Map of Dubrovnik area

The floating measuring buoy is in the bay next to the Babin Kuk zone, and the sea temperature is read at the measuring point throughout the year. At the stations of the State Hydrometeorological Institute, the daily current sea temperature can be read, while for more detailed analyses, an analysis can be ordered from the State Institute.

Monthly water temperatures in Dubrovnik, these figures show the minimum, maximum and average monthly sea temperature in Dubrovnik. Values refer to data over the last 10 years. In addition to the tabular values, the chart below shows the changes in the average sea surface temperature during the year.

Month	Avg	Min	Max
1	14.5°C	12.9°C	17.1°C
2	14°C	12.9°C	15.4°C
3	14.1°C	12.2°C	15.6°C
4	15.5°C	13.5°C	20.2°C
5	18.9°C	15.8°C	23.9°C
6	22.8°C	17.7°C	26.2°C
7	25.3°C	22.4°C	29.2°C
8	26.1°C	23.8°C	29.1°C
9	23.9°C	19.8°C	27.1°C
10	21.2°C	17.2°C	24.1°C
11	19°C	16°C	22.3°C
12	16.5°C	13.6°C	19°C

Figure 25 - Seawater temperatures in Dubrovnik

Blue sea energy for heating and cooling is taken at greater depths than 30 cm from the surface and often the project is performed immediately at the bottom to take the water as stable as possible annual temperatures. During the winter, the seabed temperature is slightly higher than the surface temperature, so it could be around 17-18 ° C. During the summer, the temperature of seawater at the bottom is slightly lower than at the surface, so it could be 19-20 ° C.

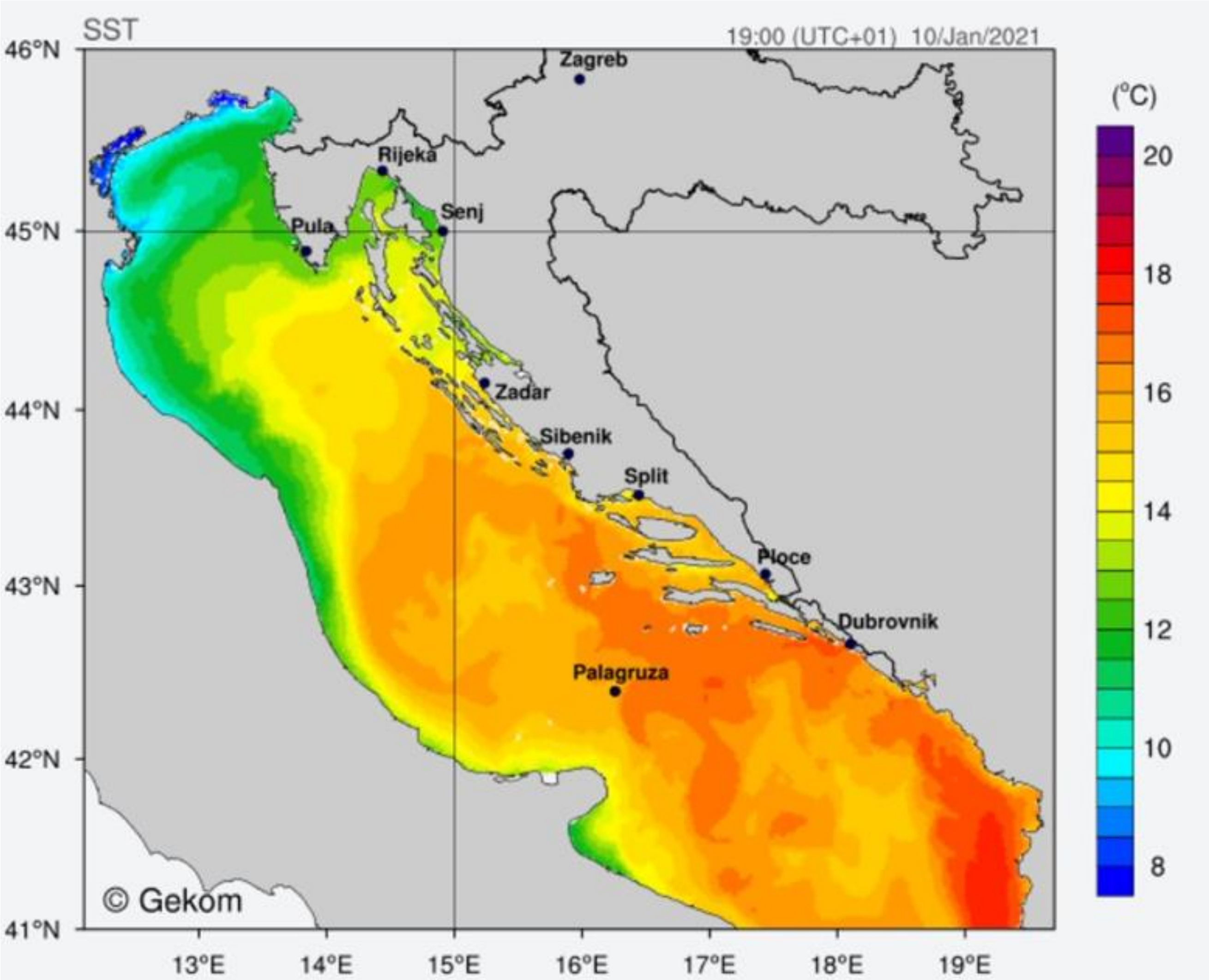

Figure 26 - Temperatures of the Adriatic Sea

2.3.2 Technical description of water-to-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, ie 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 system mode change time.

The installation is intended for use

- water-to-water heat pump
- placed 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

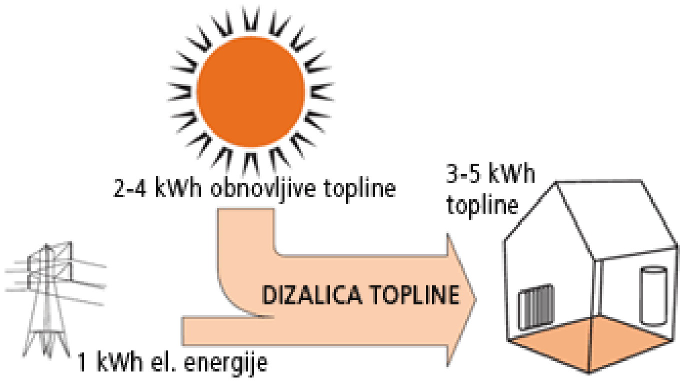

Figure 27 - Heat pump combined with solar panels that produce renewable energy

The main 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. In relation to heating using a gas system or natural gas, savings of 50-60% are achieved depending on the geoclimatic of the building location. Compared to natural gas heating, carbon dioxide emissions of CO2 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 can operate down to -25 ° C with proper sizing and sufficient groundwater depth. Compared to classic dual heating and cooling systems, the required space is saved because the unit has integrated heating and cooling and facilitates the maintenance of the system, which reduces the total investment.

The water-to-water heat pump can be used as a heat source without the occurrence of unit icing and loss of efficiency at low temperatures compared to air-to-water heat pumps. According to the initial investment, air cranes are the most favourable, but they also have the lowest efficiency and will consume the most energy for heating and cooling the building.

Water-to-water and water-to-air heat pumps use water as their heat source. The source of water can be a lake, pond, river, stream, well, or borehole that extends to groundwater. Groundwater is the most common source when we talk about heat pumps that harness shallow geothermal energy.

Water-to-water heat pumps can easily use water as a medium to heat buildings. It raises the energy obtained from the water source to a higher temperature regime, and then sends it through the building's distribution system to radiators or underfloor heating circuits.

The main advantage of groundwater is its constant temperature, which ranges between 7 and 12 ° C even on cold winter days. This temperature constancy means that the heat pump can successfully heat the building even during the coldest days. An air-to-water heat pump is not always capable of this or consumes huge amounts of energy to heat to the required temperature.

Another great advantage of using a water source, especially groundwater, is shown in summer or hot days when the heat pump can passively cool the building. This is also known as natural cooling. Cold groundwater is leaked through the building's cooling system, causing cooling.

When installing a water-to-water heat pump, we must pay attention to which water source we choose. Surface water sources can freeze, which of course prevents the operation of the heat pump. Also, the water source must not be too small, because otherwise the operation of the heat pump too much affects its temperature, and the system becomes energy inefficient. Flowing water sources, such as rivers and streams, are interesting. Their selection is less frequent because the source is limited by place and laws. They can be very energy efficient because the water is constantly changing, and the outside temperature and operation of the heat pump do not affect its temperature too much. In addition, the liquid source can freeze much harder in winter.

Technical description of the heat pipeline

The intention is that the thermal energy must be conducted to each building, and to achieve this it is necessary to conduct a heating network of flow and return water throughout the city. The heating pipeline ends in the central heating station where the pump consumption would be located for cooling or heating the transmission medium with seawater and, if necessary, the central heat pump for additional heating and cooling. The heating pipeline would run through all the streets and the connections of each building would be connected to it. Inside the building would be a local water-to-water heat pump by which the building itself is heated while the heat pump draws energy from the heat pipe in heating mode or heats the heat pipe when cooling the building.

2.4 UniCam

2.4.1 The Port of Ancona

The Port of Ancona is in the middle of the Italian Adriatic coast. The port areas cover 1.4 million sqm, articulated in passenger and ferry terminals, container, and general cargo facilities. The port has a key function in the Adriatic-Ionian Macro-Region as the terminal of the international ferry routes to Greece, Croatia, and Albania.

Figure 28 - Port of Ancona

In the area, Archaeological findings from the Mycenaean Era were recovered, testifying commercial trades with Greece since the XIII century BC.

During its history, the Port of Ancona has therefore undergone several changes necessary to accommodate boats that gradually became larger. During WWII, the city got badly damaged by bombs, that destroyed several neighbourhoods and most of the port facilities. After the war, with remarkable effort, the reconstruction of the harbour began, and because of its strategic position in the Adriatic area, Ancona gradually managed to get back on its feet.[19]

In recent years, further improvement works have been carried out at the port of Ancona such as the expansion of the NW breakwater in 2010 and the lengthening of the NE breakwater pier.

Today, the port of Ancona is one of the most vital and active harbours in the Mediterranean area and plays a primary role in trade. It is classified as an international port by the European Union, and it is part of the Scandinavian Mediterranean route TEN -T.

Through the port of Ancona over one million passengers' transit on ferries and cruise ships, heading to the eastern shores of the Adriatic (Croatia, Albania, Greece) and of the Aegean. Container traffic has grown in recent years, exceeding the 150,000 TEUs per year and attracting all the major global carriers in the container transport sector. [20]

2.4.2 San Benedetto del Tronto

San Benedetto del Tronto is the southernmost coastal town of the Marche region, on the border with the Abruzzo region. Its population is about 50,000 inhabitants and it is an important tourist centre on the Adriatic coast with about 10 km of coastline.

Figure 29 - San Benedetto del Tronto

Also, San Benedetto del Tronto hosts the second largest port in the region, home to several shipyards and especially fishing boats, making it one of the most important fishing centres in the Adriatic. The Sentina Natural Regional Reserve, the smallest Park in the Marche region established in 2004 by regional law, is located south of the town. From the environmental point of view, Sentina is considered a homogeneous system of land, river, and lake areas, a landscape of waters and sand covering an area of 177.55 ha. The

Reserve represents San Benedetto del Tronto an invaluable treasure for its natural environments, life quality, and a differentiated tourist offer completing the already existing proposals offered by the seaside tourism. The Sentina Regional Natural Reserve is characterized by about 1700 meters of coastline along which there is a small dune system with natural vegetation. This environment is severely at risk due to coastal erosion, which prevents its natural evolution.

2.4.3 The Blue energy potential

As mentioned above, the two selected sites fall into two different sectors of the Marche coast. For this reason and the morphological differences between them, to calculate the energy potentials of the two sites, the data collected by the wave buoys of Ancona, for the Port of Ancona, and the port of Ortona for San Benedetto were analysed [21]. The analysis has shown that despite the distance between the two buoys and the difference in depth at which they are anchored to the seabed, the recorded wave motions are very similar to each other. In fact, in the periods in which both buoys worked the significant characteristics of the waves are almost the same. The only difference to take into consideration is the orientation of the coast concerning the direction of the waves. For the Port of Ancona, we considered the breakwater pier in the NE sector of the harbour. The hourly sea states useful for calculating the energy potential have been processed, discarding the waves with a non-exploitable direction. The results of these analyses are visible in the figures below.

H_0(m)		Tp(s) 1	2	3	4	5	6	7	8	9	10	11
0	0.5	0	0	812	2314	510	74	12	6	5	1	0
0.5	1	0	0	37	912	1072	243	36	6	0	0	0
1	1.5	0	0	0	66	422	250	51	10	1	0	0
1.5	2	0	0	0	1	86	163	44	8	0	0	0
2	2.5	0	0	0	0	25	63	50	4	0	0	0
2.5	3	0	0	0	0	1	18	43	7	0	0	0
3	3.5	0	0	0	0	0	11	64	68	0	0	0
3.5	4	0	0	0	0	0	0	36	76	1	0	0
4	4.5	2	0	0	0	0	0	11	36	7	0	0
4.5	5	0	0	0	0	0	0	2	8	9	0	0
5	5.5	0	0	0	0	0	0	0	0	4	0	0
5.5	6	0	0	0	0	0	0	0	0	0	1	0
6	6.5	0	0	0	0	0	0	0	0	0	0	0

Figure 30 - Port of Ancona sea state.

H_0(m)		1	2	3	4	5	6	7	8	9	10	11
0	0.5	0	0	738	2104	464	62	11	5	4	1	0
0.5	1	0	0	34	829	893	221	33	5	0	0	0
1	1.5	0	0	0	55	384	227	46	9	1	0	0
1.5	2	0	0	0	1	72	148	40	7	0	0	0
2	2.5	0	0	0	0	21	57	45	3	0	0	0
2.5	3	0	0	0	0	1	16	39	6	0	0	0
3	3.5	0	0	0	0	0	10	53	62	0	0	0
3.5	4	0	0	0	0	0	0	30	69	1	0	0
4	4.5	1	0	0	0	0	0	10	30	6	0	0
4.5	5	0	0	0	0	0	0	2	7	8	0	0
5	5.5	0	0	0	0	0	0	0	0	4	0	0
5.5	6	0	0	0	0	0	0	0	0	0	1	0
6	6.5	0	0	0	0	0	0	0	0	0	0	0

Figure 31 - San Benedetto sea state.

Analysing the data reported in the tables, it is noted that the characteristics of the main waves are comparable, and the only difference is the number of waves recorded, which in the case of Ancona are about 10% more.

Also, 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. As already written in D3.4.1, the data obtained by the RMN (Rete Mareografica Nazionale) [22] show a difference of 1°C between the mean temperatures recorded in the survey station located in the Port of Ancona in the northern sector and the one located in the Port of San Benedetto del Tronto in the southern sector. The chart in figure 32 shows the data relating to the Ancona station. 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.

As for the data recorded in San Benedetto del Tronto (Fig.33), 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.

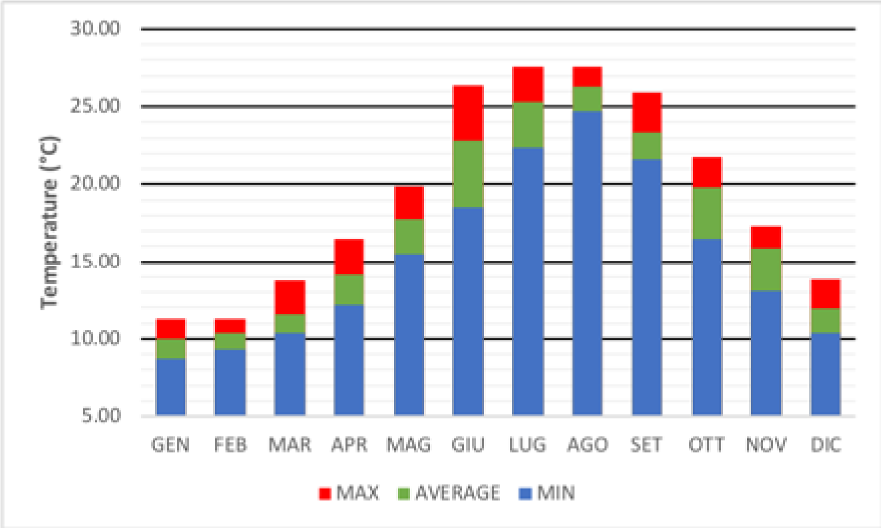

Figure 32 - Annual sea temperature variation in Ancona

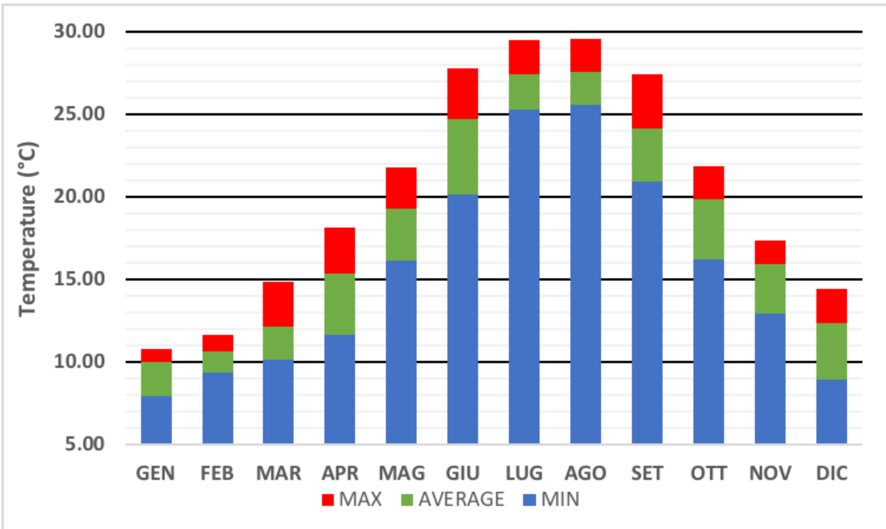

Figure 33 - Annual sea temperature variation in San Benedetto del Tronto.

2.5. UniUd

2.5.1 Preliminary considerations

Before proceeding with the analysis of the pilot area, it is important to have in mind some fundamental principles that underlie the use of the hydrothermal resource in surface water bodies. It is important to consider that all seas are thermal energy accumulators. In deep seas, the average temperature at the bottom is constant, while the Adriatic Sea is characterized by a sea bottom temperature that is affected by the season and the influences of water. Therefore, the Adriatic Sea has a much higher temperature variability. The Gulf of Trieste plays an important role in the evolution of the hydrological characteristics and currents of the entire upper Adriatic basin. In the summer, the supply of fresh water from rivers establishes a clear stratification between the surface waters, which are warmer and less saline, and the bottom ones, which are colder and more saline. In the cold months, on the contrary, the mixing is total, with uniform characteristics between the surface and bottom waters.

The regional coastal waters belong to the northernmost part of the upper Adriatic basin and are also characterized by a limited depth of the seabed whose maximum value reaches 25 meters. Therefore, as regards the Adriatic Sea, there are three principles to consider to be able to design hydrothermal plants for surface water bodies.

The **first principle** is to make an energy balance to not discharge into the sea more heat than is taken. Discharging more heat contributes to global warming. Consequently, it is important to arrange systems that, from an energy balance point of view, recover in the winter at least as much as they discharge in the summer. Therefore, to be on the safe side you take more than what you release and then you size the systems to catch more energy in the winter than you put back in the summer.

The **second principle** is represented by the need to have inertia and a mass of seawater large enough to not produce peak loads, to not concentrate the discharge or withdrawal of energy in a small area, since it would not be able to dissipate quickly. Therefore, to overcome the concentration of water it is necessary to have a certain water exchange dimension.

The **third principle** is to ensure proximity between source and user, both for an economic problem and a dissipation problem. Consequently, the use area of the thermal energy produced must not be too far away from the body of water, to not excessively affect the cost/benefit ratio, due to the works necessary for the connection. Finally, it is important to establish distribution centres and not networks on a global scale.

2.5.2 Technical requirements

Following the analysis of the regional territory of Friuli Venezia Giulia, some main problems have emerged to install hydrothermal systems for surface water bodies.

Sea level rise: ENEA's forecasts indicate a rise of 80-120 cm in 2100. If the forecasts were true, the regional coastal area could start to have problems, the Trieste area as Piazza Unità d' Italia. In 1967 there was a sea rise of 1.97 meters above the average level. In 2019 the rise hit the city of Venice. It is expected that the rise will affect the entire area which includes: Lignano, Grado, Marano, Portopiccolo, Monfalcone.

Waste of freshwater resources: in the region, there is a waste of freshwater, high-quality mineral water which is replaced with water titrated to atrazine rather than hydrocarbons, heavy metals, etc. This is because, throughout the coastal area, many inhabitants use wells for water withdrawal because there is no aqueduct or because they use wells for irrigation. The legislation on the use of wells for the withdrawal of freshwater refers to a Royal Decree of 1936, which authorizes the landowner to drill a well for his own needs, related to agriculture and livestock.

The interface of the saline wedge between salt water and fresh water: a wedge is formed inclined towards the land because seawater is denser than freshwater. The wedge stops when it is counterbalanced by the thrust of freshwater, inside a permeable area. If the inhabitants withdraw freshwater for irrigation or tourism purposes using wells, the hydraulic load is reduced, and a horizontal flow of water is activated (the flow goes from where there is the highest load to where there is the lowest load). Then the salt front advances. There is a risk that brackish water will be caught from the wells.

The problem of authorizations for the withdrawal of water from the sea: the authorization for the withdrawal of water from the sea is a long procedure that was under the responsibility of the Ministry. Currently, however, it has been delegated to the Autonomous Region of Friuli Venezia Giulia.

In conclusion, we can say that we are not designing in stationary conditions, but we are designing in highly variable conditions. This translates into a problem of sustainability of the use of the resource: if you have salted an area that was previously characterized by freshwater, it will take a century to reverse the process.

Procedure for installation

Another aspect that must be kept in mind for the selection of the potential pilot area is to proceed with a mapping of what is already available in the considered area. Therefore, it is important to proceed in three steps:

1. Resource mapping;
2. Users mapping;
3. Technology mapping.

Regarding the first of these, as already mentioned above, one of the design principles is the availability of a sufficiently large mass of water to avoid having peak loads. Other aspects to consider are the currents and the need for water flows. The Gulf of Trieste plays an important role in the evolution of the hydrological characteristics and currents of the entire upper Adriatic basin, being one of the sites for the formation of particularly cold water. The high latitude, the limited depth and the presence of large continental masses determine an exaltation of the thermohaline stratification phenomenon for the water masses of the Gulf of Trieste.

In summer, the presence of freshwater poured from rivers and surface heating cause a clear stratification of the water column. On the surface, there are warmer and more diluted waters, while denser and colder waters remain confined in depth. However, in winter due to the lower thermal radiation, the water is completely mixed, and the chemical-physical and biological quantities are comparable along the water column.

The circulation of water masses in-depth almost always occurs counterclockwise with very low speeds (2-3 cm/s), while on the surface the water generally moves clockwise. The speed of the surface layer increases in the presence of winds from the sea and decreases with the prevalence of land breezes.

The characteristic of the terrain is also a key element to consider when we refer to the mapping of resources. This is because the subsoil is an excellent thermal warehouse. You can put the heat underground because the earth is refractory, in other words, you accumulate heat which you will then take back when you need it. In this case, the characteristics of the rock mass present underground plays a key role.

Secondly, it is necessary to map the current and future users who could benefit from this type of system. There are four main users:

1. Civil;
2. Agricultural (for example land or farming areas in the lagoon);
3. Therapeutic bath – tourist (usually close to inhabited areas, extremely important and interesting in these parts);
4. Low absorption industrial (e.g., dryers, fruit, vegetables).

Finally, it is important to carry out a mapping of technology. An evaluation will then be carried out to identify precisely the most suitable solution from a technological point of view.

2.5.3 Pilot area analysis

The Gulf of Trieste is the pilot area chosen in terms of energy efficiency. The area is more convenient from a functional point of view because it has water flows, water pulling, and it is possible to take advantage of freshwater. The project solution of exploitation of hydrothermal energy from marine sources in a seaside city like Trieste arises from the availability of a resource immediately adjacent to the urban area. A second reason is the opportunity to implement the use of renewable sources in public and/or private buildings of the historic centre on the seafront.

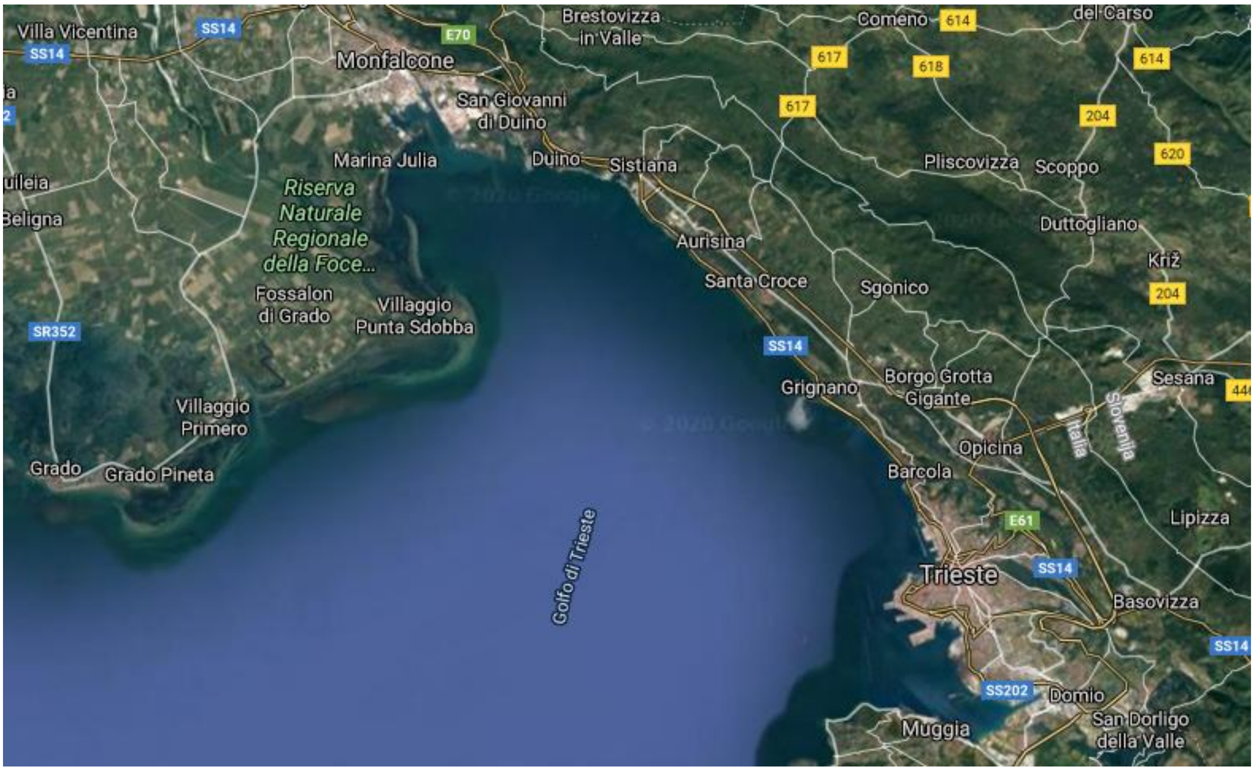

Figure 34 - Gulf of Trieste

2.5.4 Selection of pilot location

In detail, our pilot project has a pilot location Piazza Unità d'Italia.

The square has a rectangular plan with a total area of 12,280 m². The square opens on one side onto the Gulf of Trieste and is surrounded by numerous palaces and public buildings, the headquarters of various bodies: the Trieste town hall, the building of the Regional Council of Friuli Venezia Giulia and the prefecture of the capital.

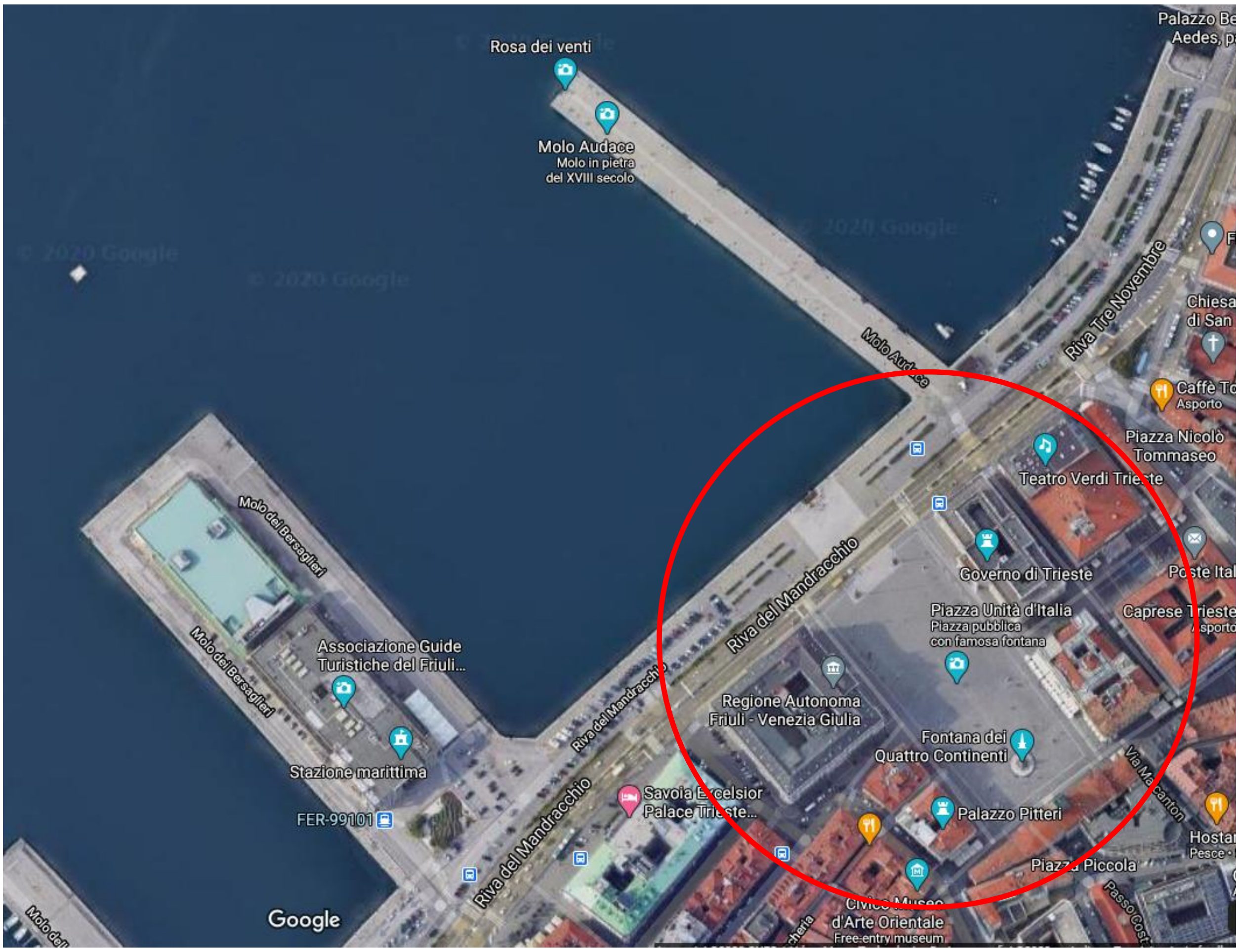

Figure 35 - The pilot area

The historic centre of Trieste is characterized by its proximity to the sea, a basin characterized here by a depth of about ten meters and by a temperature with limited variations throughout the year: 14-16 ° C in summer and 9-11 ° C in winter.

Figure 36 - Piazza Unità d'Italia

2.6. Chieti-Pescara

2.6.1 Selection of areas

The two pilot areas selected concern Pescara Marina and Vasto Marina.

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. The Chamber of Commerce of Pescara-Chieti is the authority currently in charge of the management of the Marina.

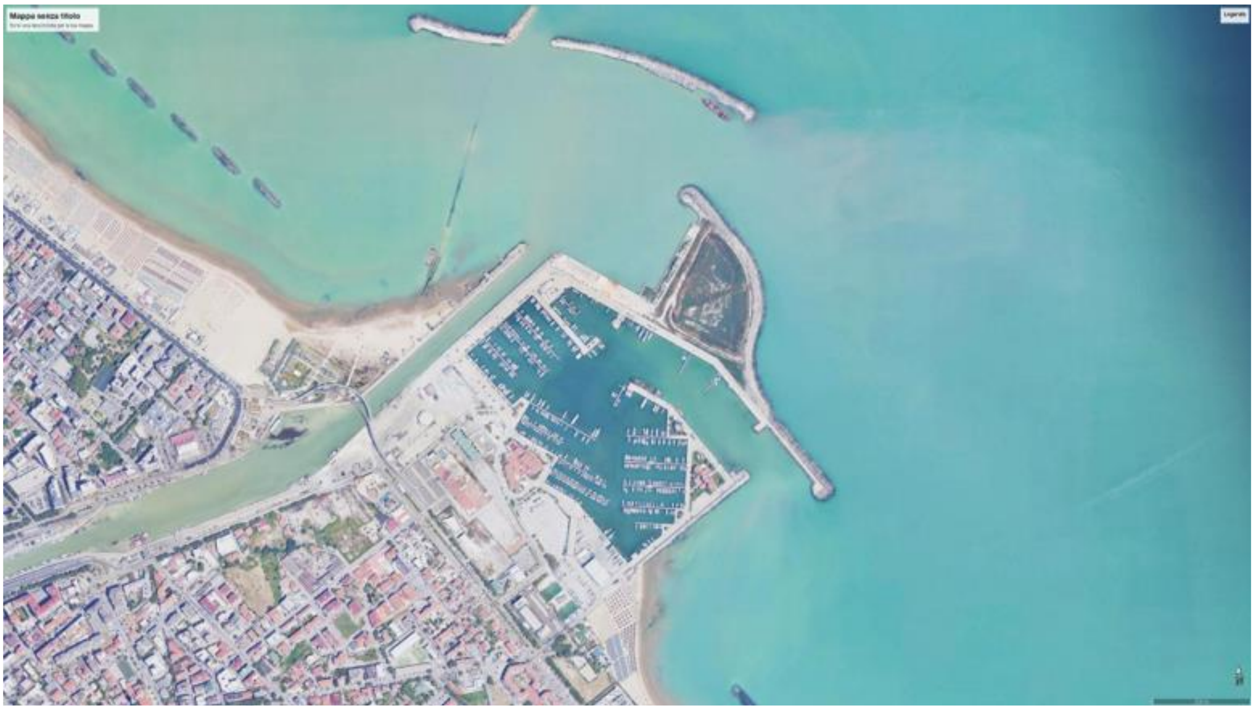

Figure 37 - Pescara Marina: current state

The Marina of Vasto is a multifunctional port with commercial activities (e.g., transport of dry materials, vegetal oil, gasoline) 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 38 - Vasto Marina: current state.

2.6.2 Technical requirements

Regarding onshore wave energy converters, the most suitable technologies include:

Oscillating water columns – Two main references exist for this technology: the plant installed in the Civitavecchia harbour (Italy), namely REWEC3, and the plant in the Bay of Biscay (Spain), namely Mutriku. In general, an OWC can be installed in new or existing piers, with bathymetry ranging from 2.5m to 15m (highest bathymetry makes it inconvenient) and a minimum wave height of 0.5m is generally required for assuring the productivity of the plant. The external wall ranges from 5 to 8 m high. In 100 m are usually installed from 18 to 24 air turbines, one per chamber, from 10 to 20 kW each. Based on a few data available in the literature, the electricity production yield can be hypothesized from 250 to 500 MWh/yr per 100m piers. This is reasonable also for the Adriatic coast, even if a more detailed assessment is needed depending on site-specific data monitoring. The technology is at a high technology readiness level, but proper testing of air turbines is still needed.

Overtopping Breakwater systems - The main reference for this technology is the prototype installed in the harbour of Naples (Italy), namely OBREC, and some theoretical systems published and simulated through models. In general, an OBS can be installed in new or existing piers by replacing common breakwater barriers with stones or tripods. This system requires a minimum wave power of 25 kW/m (wave height should be around 1 m) for assuring the productivity of the plant. In 100 m are usually installed 60 kW power (it can be for example 20 turbines x 3 kW or 60 turbines x 1 kW). Based on a few data available in the literature, the electricity production yield can be hypothesized from 200 to 250 MWh/yr per 100m piers. The minimum requirements for wave height are more restrictive for the identification of suitable sites. The technology is at a medium technology readiness level, considering there are prototypes and hydro turbines that should be specifically manufactured and tested.

Wave clappers – Two main references can be highlighted for this technology: the plant installed in Gibraltar (Spain), namely Eco Wave Power, and the plant in Denmark, namely Wave Star. In general, wave clappers can be installed in new or existing piers, with bathymetry higher than 2.5m and a minimum wave height of 0.5m is generally required for assuring productivity of the plant. Floaters are like buoys with a diameter from 2 to 6 meters and an average mutual distance between longitudinal axes of 3 m. 100 m are usually installed from 25 to 33 buoys, from 10 to 30 kW each (we can hypothesize 1 MW per 100 m as an average). Based on a few data available in the literature, the electricity production yield can be hypothesized from 250 to 450 MWh/yr. per 100m piers. This is reasonable also for the Adriatic coast, even if a more detailed assessment is needed depending on site-specific data monitoring.

Seawater based heat pumps – There are several examples of these systems, especially in Slovenia and Croatia. Interesting examples made by a team of researchers at IUAV exist with application to cultural heritage buildings in Venice with evidence of the good performance of systems that exploit the water of the lagoon, compared to the most common air-based heat pumps. In general, seawater-based heat pump systems show a coefficient of performance of CoP > 4. This value suggests the opportunity to use heat pumps for a transition to electrical heating/cooling systems in buildings although, from an environmental viewpoint, this should be supplied by renewable energy sources to be sustainable.

2.6.3 Selection of pilot locations and technology applications.

The following sections highlight the most suitable sites for the installation of wave energy converters in Pescara Marina and Vasto Marina. The pilot projects 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.

Regarding heat pump systems, a detailed analysis of all the existing buildings in the Marinas and their energy retrofitting through renovations and heat pump systems should be discussed with stakeholders during dedicated meetings. The production of electricity through waves and the use of heat pumps for heating/cooling buildings would contribute to the transition of the Marinas to electric systems fully or partially supplied by renewable sources.

2.7 Community of Mediterranean Universities

The Apulia Region has 870 km of coastline divided between the Adriatic Sea to the East and the Ionian Sea to the West. It is among the Adriatic Italian regions with the most favourable conditions for the development and implementation of Blue Energy. Indeed, its marine energy potentials are above the average of the rest of the Adriatic, and its seabed, unlike those of the central and northern Adriatic, reaches important depths even at a short distance from the coasts.

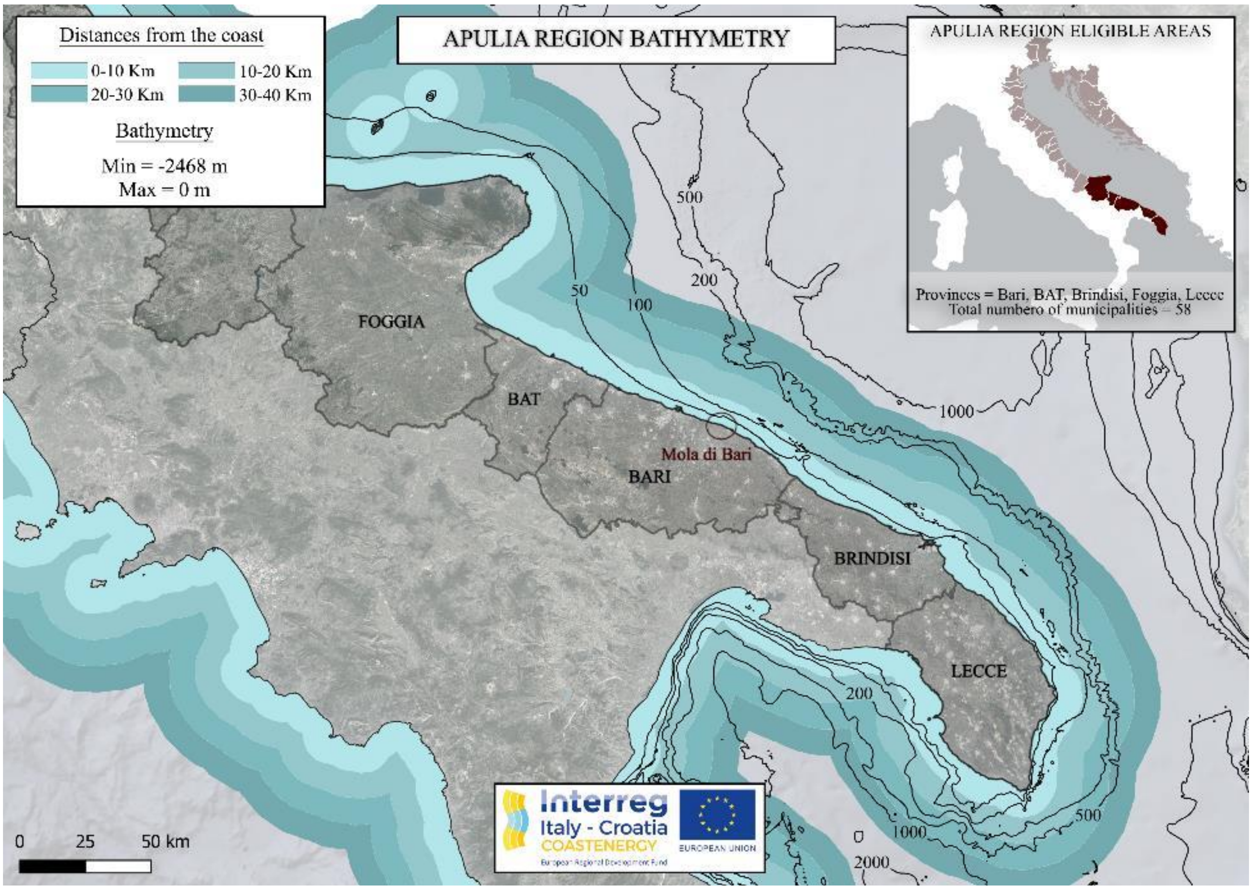

Figure 39 - Bathymetry off the Apulian coasts.

The port of Mola di Bari has been chosen as the pilot area for CMU not only thanks to its favourable physical characteristics but also because the local authorities are already willing to enhance the city waterfront, including the port area, with several integrated initiatives, continuing what already undertaken years ago with the "Urban" Programme, co-financed by the European Union.

Figure 40 - Municipality of Mola di Bari.

Among the various projects that the municipality is already involved in, the Interreg V-A Greece-Italy "AI SMART – ADRIATIC IONIAN SMALL PORT NETWORK" project should be mentioned. It aims at implementing and developing a common port network in the Adriatic-Ionian area, based on the concept of "smart, green and integrated port" and aimed at connecting the small ports of the two countries, also including that of Mola di Bari as a strategic node. This project entails the mapping of the local multi-modal transport services, especially those concerning the connection between the tourist port and the city, and the programming of infrastructure projects for the redevelopment of the port area.

Another project involving the coastal area is the "Waterfront 2nd set (urban beaches)", entailing the urban redevelopment of the northern waterfront between Portecchia and Porto Colombo.

Figure 41 - Port redevelopment projects for Mola di Bari.

Finally, the entire port area will be affected by a further project called "*dalla città porto al porto città*", consisting of the construction of a district built on piles. This project entails the objective of making the entire area of the "big port" self-sustainable in terms of energy.

The COASTENERGY pilot project intends to be part of this general framework and to contribute to the energy supply for the floating district and the pier.

The technologies proposed for the pilot project have been selected considering both their technical and financial feasibility, and their low environmental and landscape impact.

2.7.1 Selected Technologies

The wave and tidal energy sectors are currently exiting the research and development stage and entering the pre-commercial and commercial stage.

Although the availability of marine energy sources in Europe is higher along the Atlantic coasts, the Mediterranean has been also recognised as an environment offering significant opportunities for energy production and related technological development. The Mediterranean is mainly favoured by its characteristics of mild climate conditions, which make it possible to test the cost-effectiveness of the devices and stimulate the search for specific technologies that are particularly efficient for this area.

Moreover, the considerable fragility of the Mediterranean environment requires efforts to promote the development of innovative technologies capable of supporting the energy independence and sustainability of particularly exposed habitats, ecosystems, and communities, such as those located in small islands, offering new options and solutions for the mitigation to climate change.

In the Blue Energy sector, Italy has progressed significantly in the research and implementation of devices, acquiring a prominent position among the international insiders.

However, the enormous potential offered by the Blue Energy sector in terms of environmental sustainability, economic growth, creation of highly skilled jobs, and strategic positioning of the national industry in the global competitive market is still hindered by inadequate and complex legislation, which generates uncertainty about institutional competences and the actual applicability of these energy devices both on the coast and at sea.

Support to the development of Blue Energy would also meet the recommendations and directives of the European Union, which established a common framework for the Member States to promote the use of energy from renewable sources (Directive 2009/28/EC), as well as a framework for the implementation of marine spatial planning and integrated coastal management by the Member States, to promote the sustainable growth of their economies, and the development and sustainable use of their marine resources (Directive 2014/89/EU[5], and Italian implementing decree[6] D.lgs 17/10/2016 n. 201).

To determine the most suitable choice for the local context, the first step has been carrying out general analyses and gathering information on as many Blue Energy technologies as possible. This first step was necessary to clarify their operational modes and identify the most promising in terms of technology readiness. The analysed energy sources are:

- converters extracting kinetic energy from tidal currents;
- converters exploiting the difference in energy potential deriving from the rise and fall of the sea level between high and low tide (tidal interval);
- wave energy converters, extracting kinetic energy from the waves pushed by the wind;
- ocean thermal energy converters, exploiting the temperature differences between deep and surface ocean waters;
- salinity gradient converters, exploiting the chemical potential of differences in salt concentration in the waters.

5 http://www.mit.gov.it/normativa/direttiva-numero-201489ue-del-23072014

6 https://www.gazzettaufficiale.it/eli/id/2016/11/07/16G00215/sg

For each of these energy sources, the global industry has developed multiple technical solutions, adapting existing technologies or designing innovative devices. However, most of the technologies were initially developed for the oceans and found application in the northern seas.

Only in recent years, there has been a proliferation of technologies that are also applicable to milder marine environments, such as the Mediterranean basin. As regards wave energy, for example, the focus was shifted to the exploitation of the wavelength rather than the wave height, since the wave motion in the Mediterranean – particularly the Adriatic Sea – is characterized by the formation of waves with considerable lengths but reduced heights. The Italian industry and research have indeed developed a growing interest in the sector of wave energy converters.

To narrow the search for technologies applicable to the Mediterranean, an analysis was made of the physical and environmental differences between the northern seas and the eligible areas of the COASTENERGY project. These differences concern in particular:

- wave height;
- depths of the seabed;
- speed of the currents.

As regards wave heights, whereas in the northern seas they can reach 18 m, they usually do not exceed 8 m in the Mediterranean. Depths are also lower in the Mediterranean; moreover, there are considerable differences within the Mediterranean itself, with the Adriatic Sea being shallower than the Tyrrhenian and the Ionian seas and having slower currents and lower wave power. However, the Apulian coast has the advantage of having greater depths and greater potential compared to the Central and Northern Adriatic.

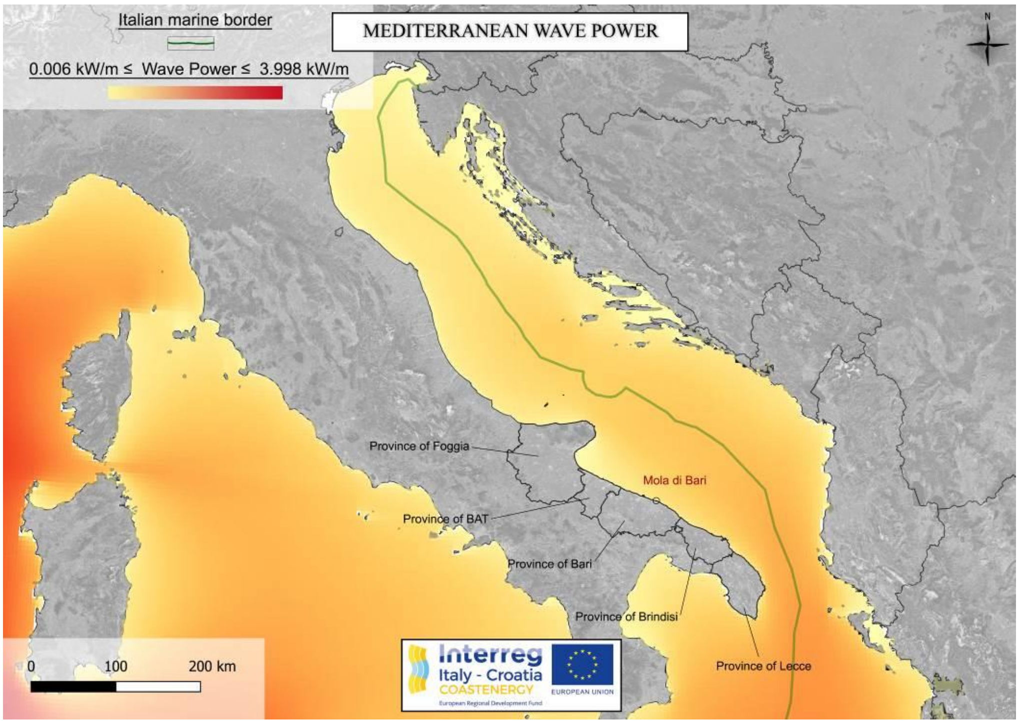

Figure 42 - Wave power in the Mediterranean.

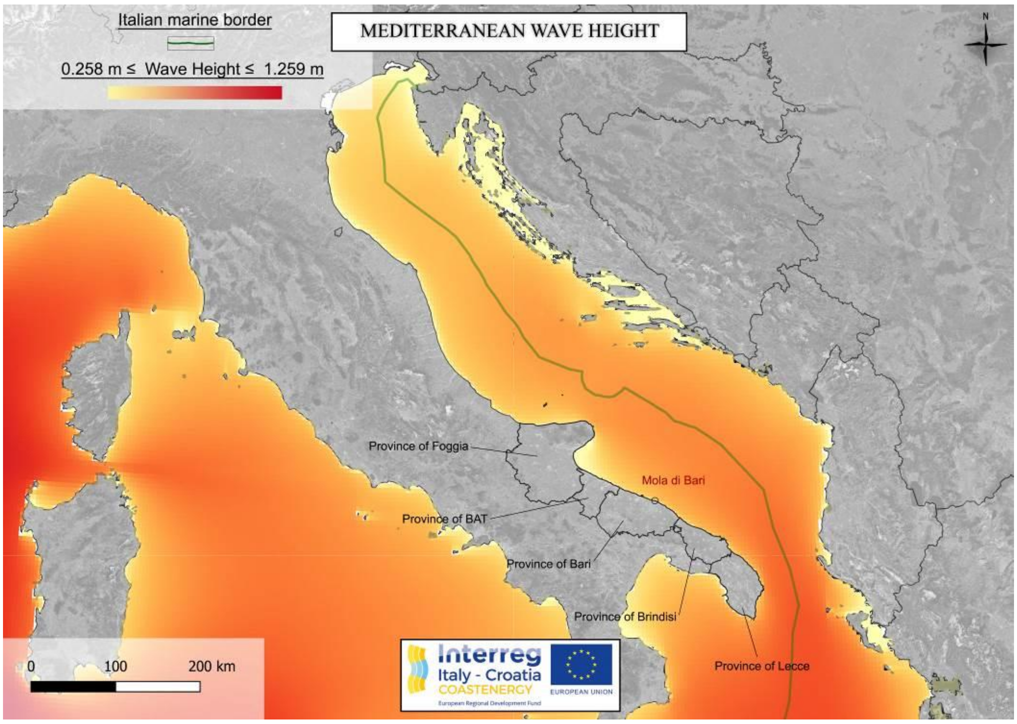

Figure 43 - Wave heights in the Mediterranean.

The Apulia Region, due to the presence of several areas of environmental and landscape value, is affected by a high number of restrictions, especially along the coast.

To cope with the needs for environmental protection along the coast, the Region has adopted the Regional Coastal Plan (PRC). This tool regulates the use of the areas belonging to the maritime state property, to ensure a correct balance between the environmental and landscape protection of the coastal areas, their free use, and the development of recreational and tourist activities.

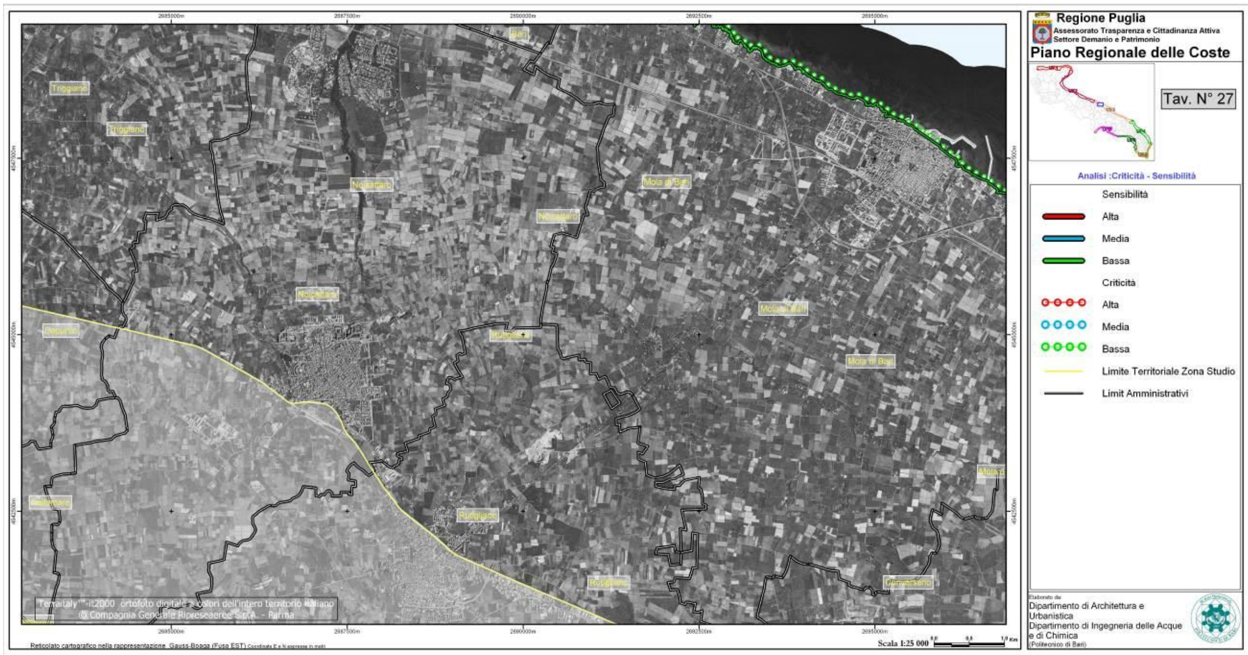

Figure 44 - Regional coastal plan: analysis of criticalities.

Within a general framework of integrated coastal management, the Plan pursues the objective of the economic and social development of the coastal areas through criteria of eco-compatibility and respect for the natural processes. The Plan also contains a classification of homogeneous coastal and marine sectors and sub-sectors, called Physiographic Units and Sub-Units, allowing for monitoring of their evolution and the effective identification of the needed recovery actions.

The pilot area of Mola di Bari, and the specific locations for the pilot projects, have been selected considering all the environmental, technical, legislative, and institutional conditions described above.

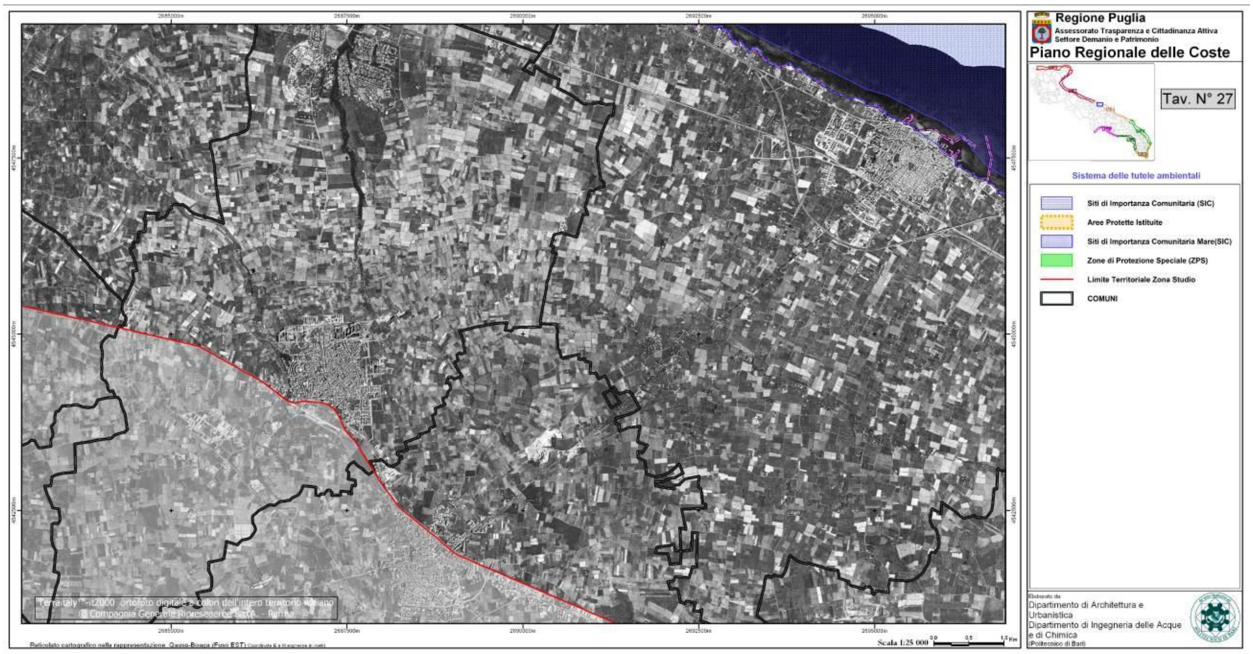

Figure 45 - Regional coastal plan: environmental protection system.

After the first step of selection of possible technologies and pilot locations, three technologies have been specifically selected: two off-shore technologies (**ISWEC** and **Penguin**), and one on-shore technology (**OBREC**). This choice has considered:

- the advanced technological development of these technologies (all of them already operational), also to be able to obtain real productivity data, based on which a proper installation proposal could be made;
- their low environmental impact: in particular, the ISWEC and Penguin technologies do not require important mooring structures that could be a threat for the Posidonia meadows and the delicate seabed; and the OBREC technology can be easily integrated into existing or planned piers.

ISWEC

The ISWEC technology is the result of research carried out by the Turin Polytechnic and the Wave for Energy company, later supported by ENI. It consists of a small boat to be moored not far from the coast.

Figure 46 - ISWEC device.

This solution is very interesting for the COASTENERGY project since it was designed to adapt to the environmental characteristics of the Mediterranean and is also suitable for the Adriatic Sea. Indeed, the large systems developed for the ocean environment would not yield acceptable results – in terms of costs of the energy produced – in the Mediterranean. The available power in the European oceans – normally referred to as the unit of length of the wavefront – varies from 25 kW/m (Canary Islands) to 75 kW/m of the Irish and Scottish coasts, whereas in the Mediterranean Sea it is between 4 and 11 kW/m.

Rather than the wavelength, ISWEC exploits the wave frequency. It works thanks to an inertial system exploiting the wave motion: the waves cause a movement of the hull that is transmitted to two metal flywheels of 10 tons each, which, thanks to the gyroscopic effect, produce a motion capable of generating electric energy. It is also possible to tune the machine according to the variations in the state of the sea. One of the advantages of this technology is that its mechanical parts are not exposed to the harsh marine environment (which happens for most of the other wave energy systems), thus being safe from corrosion and deterioration; they are located in a sealed chamber and do not come into direct contact with water.

The raft containing the gear has an area of 120 sqm (8 m x 15 m) and a height of 4.5 m (of which 3.2 submerged), with a nominal power of 100 kW and a weight of 300 tons. While in operation, it remains 80% submerged: the only visible parts are the floating platform with signal lights, with low visual impact. Other advantages are the very little need for maintenance, and the high energy efficiency, with a peak power of 51 kW registered by the prototype.

All lab and field tests gave extraordinary results in terms of production and reduced installation and maintenance costs, leading to the best economic yields and the lowest LCoE. The tests on the module installed in 2015 off Pantelleria would have allowed producing electricity at a more competitive cost than that currently required to produce electricity on the island.

In October 2019, in the presence of the Prime Minister, ENI, Cassa Depositi e Prestiti (the national institution financing investments by public authorities), Fincantieri and Terna (the national grid operator) joined forces to create a new company for the construction of the first ISWEC industrial plant that will be completed near ENI's Prezioso platform in the Strait of Sicily, off the coast of Gela, with a launch scheduled for the second half of 2020. This interest by some of the most important national companies and institutions gives evidence of the actual potential of this technology and its market development. Its transferability to the COASTENERGY area is already underway with the installation of a module in the Ravenna marina, supporting the energy needs of the ENI offshore platform.

Figure 47 - Iswec Device in operation.

Following the launch in the offshore of Gela, and with the formal constitution of the new company, in addition to drawing up a plan for the production and development of activities, new devices will be installed off the coast of some minor Italian islands (including the Tremiti Islands belonging to Apulia) and off the eastern shore of the Adriatic.

In a nutshell, the reasons that make this system an interesting model to be taken into due consideration for the COASTENERGY project are:

- the gyroscopic technology is suitable for seas characterized by a wave frequency that is higher than in the ocean environment, and typical of closed seas;
- the reduced landscape impact of the raft, which emerges only about one meter from the surface of the water;
- almost no impact on the marine environment;

- the reduced maintenance costs, since only the hull is in direct contact with the water, and since the system can be positioned at a short distance from the coast and is therefore easily accessible;
- the economic sustainability: as demonstrated by the tests carried out to date, this technology aims to quickly reach the "grid parity", having, therefore, great potential for implementation on the Mediterranean coasts. ISWEC is an ideal candidate – also chosen by Terna – to launch a program of industrial-scale implementation.

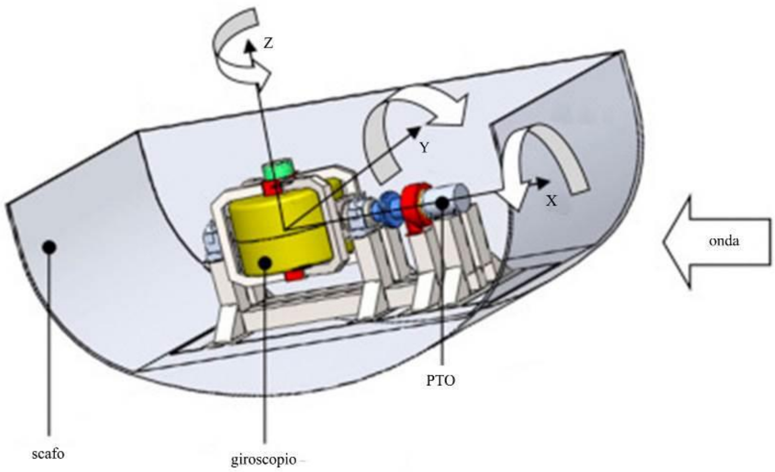

Figure 48 - Scheme of the ISWEC device.

The problems that the system could encounter are related to the positioning of the raft and the cable connecting the raft to the coast for transferring the energy, which is placed on the seabed; in the development phase, the possible interferences with fishing and recreational boating activities must therefore be solved. Another problem can derive from the possible need to obtain authorisations for the construction of the transformer substation on the coast.

Penguin

The Penguin technology was developed by the Finnish company Wello. Penguin Wave Energy Convert was built as part of the Clean Energy from Ocean Waves (CEFOW) initiative (funded by the European Union's Horizon 2020 programme), which entails the installation of up to three clean energy generation plants by the end of the decade. The system works by converting, through its asymmetrical hull, the movement of the waves into rotations which are subsequently amplified to drive the internal rotor. The device is equipped with direct conversion: wave power is transformed into electricity, which is directly fed into the grid. It can also be managed remotely and withstand waves up to 18 meters high.

The first large-scale prototype, WEC1, began testing in the Orkney Islands (Scotland) in 2012. A second prototype, the WEC2, was installed in Armintza (Basque Country) in June 2019.

Penguin WEC2 is Wello's first commercially available full-scale wave energy converter.

Figure 49 - Penguin device.

Figure 50 - Penguin device.

Unlike WEC1, installed on the Orkney Islands, which has a nominal power of 500 kW, the Basque Penguin (WEC2) has undergone numerous improvements, from the design to the type of mooring, as well as a reduction in scale that allows it to reach a nominal power of 600 kW.

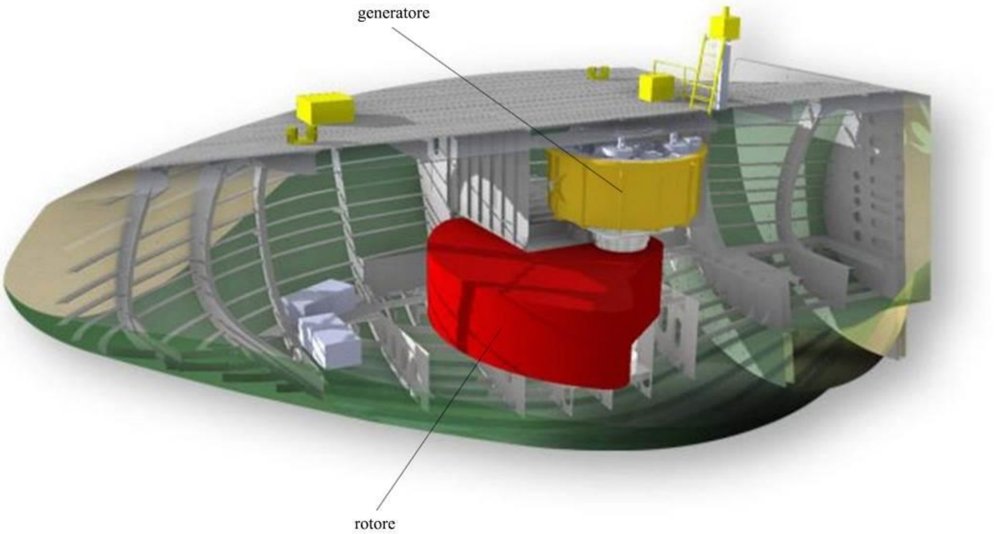

Figure 51 - Scheme of the Penguin device.

As part of a Memorandum of Understanding, signed in last September by the Italian company Saipem and the Finnish company Wello, the former will take care of transporting WEC2 from the Orkney Islands, where it is currently located, to the Biscay Marine Energy Platform (BiMEP), a delimited area in the open sea dedicated to the research and testing of floating devices for renewable marine energy.

Thanks to its long experience in executing offshore projects in harsh environments and the field of naval engineering, Saipem will support Wello in optimising the installation procedure and operational phase of the WEC Penguin technology. This synergy will allow obtaining a competitive advantage and seizing the commercial opportunities offered by this sector. Saipem is also studying further applications of this technology to the traditional oil and gas infrastructures such as offshore platforms.

Saipem intends to become a key player in the field of marine energy, a renewable source that, soon, will play a crucial role in the energy transition. It is currently engaged in scouting the most innovative and promising technologies available on the market and providing technological and financial support for their development to make them suitable for commercialisation.

Figure 52 - Penguin device.

Penguin has no moving parts that can harm marine life. Like ISWEC, it exploits wave frequency rather than height, it can be fine-tuned according to changing sea conditions, and its gear is not exposed to the aggressive marine environment that would cause corrosion and deterioration. The main system is indeed located in a sealed chamber and does not come into contact with water.

The raft containing the tools has an area of 480 sqm (30 x 16 m). The plant has a nominal power of 500 kW and the entire system weighs 1,600 tons. During operation, the visible part is a floating platform with boat lights, having a low visual impact. It is removable, does not contain dangerous liquids, does not emit electromagnetic waves, is not noisy and can be moored freely.

In a nutshell, the reasons that make this system an interesting model to be taken into due consideration for the COASTENERGY project are:

- low visual impact;
- no environmental impact;
- reduced maintenance costs, since only the hull, is in direct contact with the water, and since the system can be positioned at a short distance from the coast and is therefore easily accessible.

The problems that the system could encounter are related to the positioning of the raft and the cable connecting the raft to the coast for transferring the energy, which is placed on the seabed; in the development phase, the possible interferences with fishing and recreational boating activities must therefore be solved. Another problem can derive from the possible need to obtain authorisations for the construction of the transformer substation on the coast. Moreover, despite the extreme versatility of this technology, its applicability currently only concerns ocean environments; therefore, it could become applicable in the Adriatic Sea only after a possible future reduction in scale. This technology has been nonetheless included in this report to foster a possible interest by local companies that might be interested in contributing to the production of a downscaled Penguin device.

OBREC

The University of Campania "Luigi Vanvitelli" has developed a device called OBREC (Overtopping Breakwater for Energy Conversion). It consists of a breakwater with a front reservoir designed to capture the waves overflowing an inclined ramp to convert their kinetic energy into potential energy. The water stored in the reservoir produces energy by flowing through low-head water turbines, because of the difference in water level between the reservoir and the main seawater level.

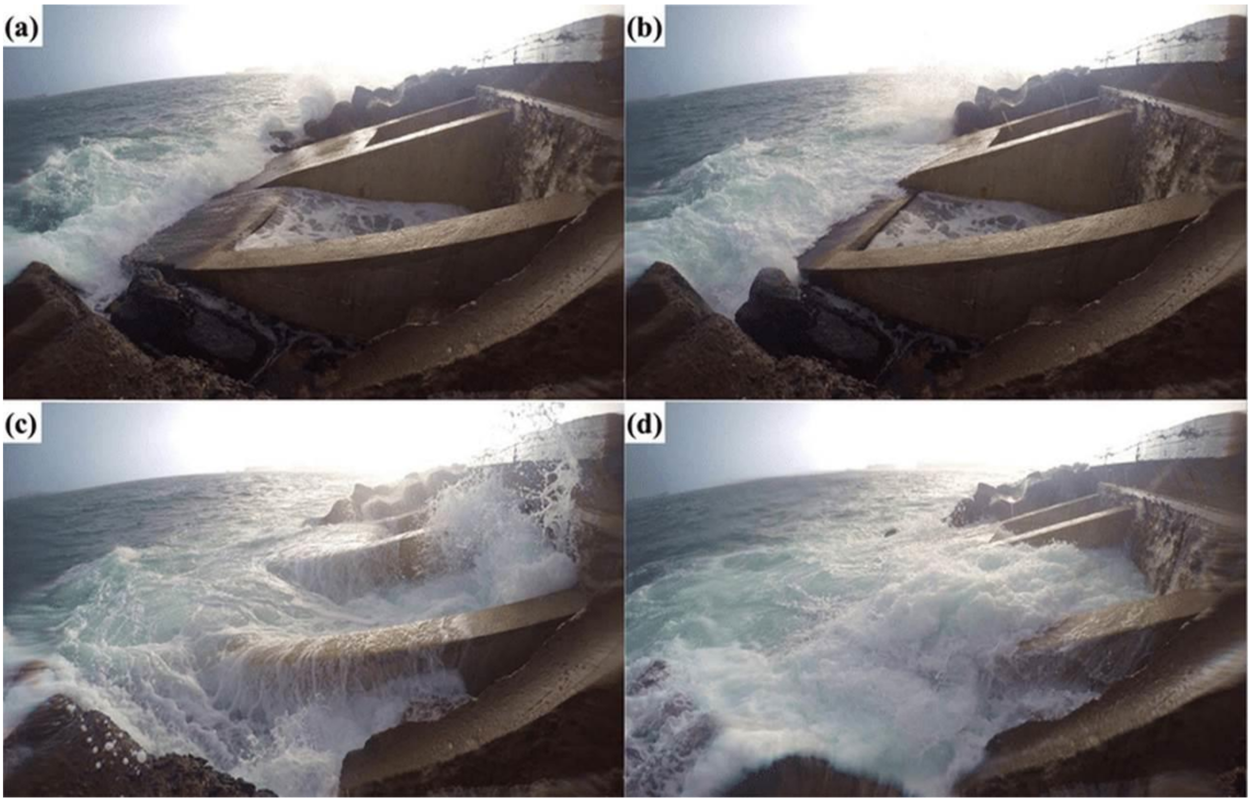

Figure 53 - OBREC device in operation.

The obtainable energy production was estimated as a function of the average discharge of water entering the front tank for different wave geometries and conditions. In 2015, a full-scale prototype of 6 metres was installed in the port of Naples, along the breakwater of the San Vincenzo mound, where the sea depth is about 25 m and the available wave power is estimated to be about 2.5 kW/m. The overall device performance is currently being monitored.

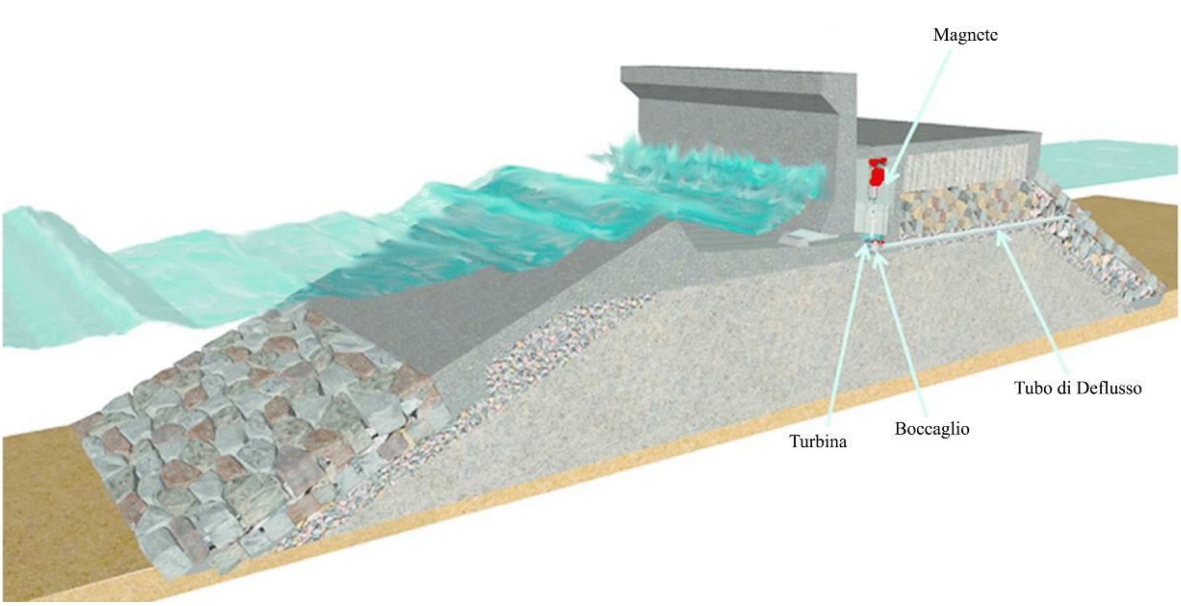

Figure 54 - Scheme of the OBREC system.

2.7.2 Technical requirements

The three selected technologies for the proposed installation in the pilot area of Mola di Bari comprise two off-shore and one on-shore device. All of them exploit the energy potential of waves. The operation of the offshore technologies is strictly conditioned by sea depth, and they can only be installed within precise bathymetric bands. On-shore technologies, on the other hand, are conditioned by the minimum energy potential of the waves, and by the possibility to be integrated with breakwaters or docks.

The elements to be considered for each of the selected technologies are:

- ISWEC: wave height must be equal to or greater than 0.5 m; sea depth must be between 25 and 50 m;
- Penguin: wave height must be equal to or greater than 0.5 m;
- OBREC: wave power must be equal to or greater than 2.5 kW/m.

2.7.3 Procedures for installation

Each technology proposed for the pilot area of Mola di Bari exploits wave motion differently. The installation procedures also differ depending on the technology: on-shore technologies are almost always built and integrated into port structures, whereas the selected off-shore technologies are remarkably easy to install since they only require cables connected to counterweights.

ISWEC and Penguin are certainly the simplest to install, even if the system for transporting the energy onshore can lead to some difficulties and interferences with other activities. Upon arrival ashore, a transformation cabin and a conversion unit will be also needed.

OBREC, on the other hand, can be used as a replacement or an integration of existing breakwaters, thus having a dual function of protecting the quay and producing energy. For its installation, it is necessary to provide building works on the pier for the construction of the technical compartment where to install the turbines.

2.7.4 Analysis of the pilot area

Mola di Bari is a town of 25,173 inhabitants in the metropolitan area of Bari, region of Apulia. Its fishing and tourist port is among the most important in the region and the entire Adriatic Sea, hosting about 350 pleasure boats and 115 fishing boats, for a total of 2,616 t gross tonnage.

The port of Mola di Bari has a long history. Its construction was authorised in 1793, even if the city and the sea had maintained a symbiotic relationship from much earlier. The first artificial pier building was used for the mooring of trading boats, which moved goods for a volume greater than that of the port of Bari. A few decades later, this work would prove insufficient, and a request for an extension was submitted. Since the 1800s and until the early 1900s, the commercial traffic progressively moved towards the port of Bari, forcing Mola to reinvent itself and focus on deep-sea fishing. The last expansion dates to 1995 with the construction of the eastern pier.

The port of Mola di Bari is currently divided into two distinct areas, Porto piccolo and Porto Grande, both consisting of two piers.

In addition to the works carried out in the port, the great dynamism of Mola di Bari and its municipal authorities led to urban regeneration plans that have affected the seafront areas. The last project, completed in July 2011, for a total of over 4 million euros, concerned about 600 meters of the Lungomare Dalmatia, in an area located north-west of the ancient town, along the urban stretch of coast extending from the pier of the Small Port that of the Big Port.

The project also included the areas comprised between the coastline and the buildings overlooking the seafront and the areas adjacent to the Angevin Castle. The project was designed by the MBM_arquitectes studio of Barcelona.

This first analysis of the pilot area underlines the close relationship that its community has always had with the sea, and the value that Mola attributes to its marine areas. The availability of the public authorities is certainly an added value in the framework of the COASTENERGY project and has been one of the factors that led to the selection of this area for the pilot projects.

2.7.5 Selection of pilot locations

The Municipality of Mola di Bari is one of the two Apulian municipalities involved in the “AI SMART – ADRIATIC IONIAN SMALL PORT NETWORK” project, which aims to create a cross-border network of tourist ports, creating the conditions for their redevelopment. In connection to this project, the municipality is planning different types of interventions:

- renovation of the buildings intended for the port authority’s offices;
- rationalisation of spaces for pedestrian and cycle mobility;

- creation of new functional spaces for tourism and commerce activities and services;
- physical and functional connections to the city seafront;
- making the breakwaters safe for public use;
- adaptation and integration of technological network systems;
- construction of breakwater reefs;
- construction of a docking/access point for the “Metro Mare”, a short transport system of ferries connecting the municipalities of the Province.

These interventions will cover the entire port area, especially the Big Port. The project, currently in its executive design phase, has been entrusted to the Roman T-STUDIO; the cost of the works is 2 million euros, and their completion is scheduled for December 2021.

In addition to AI SMART and the connected projects, the project called “Waterfront II set (urban beaches)” is underway, entrusted to architect Oriol Bohigas – MBM Arquitectes of Barcelona. These works will complete those made in 2011, which concerned the urban regeneration of the waterfront overlooking the historic town centre.

The project benefits of a 2 M € loan granted in 2016 by the Metropolitan City of Bari and will concern the northern stretch of coast, from Portecchia to Porto Colombo, including the design of an urban beach and a large urban park for leisure and bathing activities.

The COASTENERGY pilot project is, therefore, a perfect complement to the above projects: the OBREC system would become part of the port structures themselves, with the double function of protection and energy production, while the ISWEC and Penguin devices would provide energy for the port area and the planned housing units.

2.8. Municipality of Ploce

The selection of the pilot site as well as the selection of the renewable energy system implies a detailed evaluation of the characteristics of the considered sites, available data on ownership structure, existing energy infrastructure, related energy grades, stages of technological development of renewable energy systems, related technical and performance requirements, and existing energy potentials. All the above aspects have been elaborated in detail by this study to enable the selection of renewable energy systems with the best comparative advantages.

2.8.2 Selected technology

The evaluation considered all potential offshore renewable energy sources (wave energy, sea currents, the wind above sea level, salinity gradient, and geothermal energy of the sea). Since the potential of geothermal energy of the Adriatic Sea is significantly higher as compared to other renewable energy sources it has been selected for further detailed applicability analysis.

The study highlighted the exceptional efficiency levels of seawater/water geothermal heat pumps (COP and EER), which take values between 4 and 5 (COP) and between 25 and 30 (EER), respectively. Also, the

Adriatic Sea is characterized by high thermal potential as well as by small seasonal variations in water temperature at depths greater than 60 m. Therefore, it is considered an excellent source of heat and cooling energy regardless of the season.

2.8.3 Technical requirements

The considered potentials of renewable energy sources differ concerning the technical requirements related to their implementation and exploitation. Seawater/water geothermal heat pump systems stand out as demanding technical systems, especially because they involve the construction of a system of hermetically sealed intake and outlet wells up to direct contact with seawater. The presence of fresh groundwater located between land and seawater can be an additional aggravating circumstance. The design and implementation of such systems, therefore, require a multidisciplinary approach that includes mechanical, geological, drilling, construction, and electrical skills.

2.8.4 Procedure for installation

The complexity of the procedure for the installation of renewable energy systems is proportional to the associated technical requirements. The installation of geothermal seawater/water heat pumps implies the preliminary implementation of geomorphological and hydro-technical research used to establish the implementation plan of hermetically sealed wells according to the energy requirements. The circulation of seawater through the wells is enabled by a circulation pump that supplies seawater to the seawater/process water heat exchanger placed in the heating system. The system can be additionally equipped with heat accumulators and a compressor to achieve a higher degree of energy efficiency with better control of the system operation (polyvalent heat pumps for simultaneous heating and cooling).

2.8.5 Pilot area analysis

The evaluation included the building of Dom kulture in the City of Ploce, constructed in 1962. A detailed analysis of the site condition was determined by the corresponding energy grade "E", considering the annual consumption of thermal energy and the actual climate conditions. The annual heating energy requirements amount to 182427 kWh while the annual cooling energy requirements amount to 199238 kWh. Also, it was ascertained that the air/water heat pump York YLHA 150 of heating capacity of 150 kW and cooling capacity of 145 kW has already been installed at the selected location.

2.8.6 Selection of pilot locations

The City of Ploče, as a local government, has a 100% ownership over three buildings in which the city institutions are located, namely: Dom kulture, Pučko otvoreno učilište, and Dom športova. For energy potential analysis, the building of Dom kulture, located in the proximity of the coastline, was chosen. The selected location is of great importance to the local community and is used for the organization of cultural events and touristic promotion of the City of Ploče. The other considered buildings do not have an energy grade certificate and were therefore not acceptable for this type of analysis.

3 Prefeasibility study

3.1. IRENA

For the selected pilot area of the City Palace in Poreč, it is proposed to replace the existing low-temperature boiler VIESSMANN, with environmentally unfriendly fuel oil, and the existing air-cooled compression chiller RIELLO, with a relatively low cooling factor, by seawater/water heat pump as a source of heating and cooling energy.

Fan coils have already been installed in the City Palace building as heating/cooling units, which is conducive to the low-temperature regime of the heat pump. Domestic hot water for sanitary needs is prepared decentralized via individual electric boilers. Given the small profile of domestic hot water consumption, the implementation of piping for the central domestic hot water system is not cost-effective.

The calculation of annual savings and costs of fuel for heating and cooling the space of the City Palace building and the simple payback period was carried out by a simplified method considering the efficiency of heating/cooling sources.

The analysis is based on the following assumptions:

- seawater/water heat pump operates in monovalent mode, i.e., it can deliver the energy that covers the heating and cooling load of the building;
- heating and cooling systems of the City Palace are independent of the source of heating and cooling capacity, i.e., it is assumed that all devices shown in this analysis can deliver heating or cooling medium in the required temperature regime.

These assumptions make it possible to easily determine the investment and operating costs of various thermo technical systems and that, in addition to the implemented thermal devices, there is no need to install additional auxiliary devices.

The investment costs for the implementation of the seawater/water heat pump system are:

- cost of seawater heat exchangers,
- cost of the heat pump unit,
- costs of heating energy distribution system,
- other costs (installation, maintenance).

Because fan coil units, as heating/cooling units, are pre-installed, the investment cost can be immediately reduced by the cost of the heating distribution system. Table 13 shows an overview of the investment for the considered pilot area.

One scenario will be analysed in relation to the existing, reference one. The considered scenario is the replacement of the existing oil boiler and compression chiller with a seawater/water heat pump for heating and cooling of the building with the current state of the building envelope.

Table 13 - Installation of the seawater/water heat pump - current state of the building envelope - investment overview

Investment overview for current state of building envelope – heat pump system					
	Investment description	Unit	Quantity [-]	Unit price without VAT [kn]	Total cost without VAT [kn]
1	Investigational groundwater well for piezo-test	pcs	1	88.000,00	88.000,00
2	Delivery and return well, flow capacity 10-12 l/s, depth 30 m	pair	1	278.000,00	278.000,00
3	Horizontal connection between wells and intermediate circuit heat exchanger	estimation	1	25.000,00	25.000,00
4	Intermediate circuit heat exchanger with thermal insulation and connection, thermal capacity 125 kW	pcs	1	21.000,00	21.000,00
5	Hydronic distribution section with circulation pumps	pcs	1	45.000,00	45.000,00
6	Heat pump seawater/water	pcs	1	205.000,00	205.000,00
7	Electrical equipment and installation	set	1	52.000,00	52.000,00
8	Installation costs	set	1	81.000,00	81.000,00
	Total				**795.000,00**

The table below shows the energy analysis data, as well as other input data, relevant for the calculation of savings and payback period of the seawater/water heat pump installation measure.

The values of annual heating energy required for cooling $Q_{C,nd}$, for reference and actual climate data, taken from the *Report on the energy audit of the building*, are questionable given the location of the City Palace and the frequency of use of the building cooling system (information from janitor).

For these reasons, the values of annual heating demand for cooling are assumed based on the EIHP internal data obtained from the dynamic simulations conducted in the DesignBuilder program. For the current state of the building envelope, 50 kWh/(m^{2}a) is assumed.

Table 14 - installation of a seawater/water heat pump for central heating and cooling of the City Palace building in Poreč

Scenario		Referent scenario	Scenario 1
Building envelope state		The current state of the building envelope	
Name	**Unit**	Boiler and compression chiller	Seawater/water heat pump
The energy source for heating	-	Fuel oil	Electricity
Unit	-	L	kWh
Lower caloric fuel value	kWh/unit	10,0333	1
CO_2 emission coefficient for energy source used for heating	kg CO_2/MWh	299,57	234,81
The unit cost of energy source for heating without VAT	kn/kWh	0,2847	0,8800
Seasonal coefficient of performance, SCOP	-	-	4,2
Boiler efficiency	-	0,92	-
The efficiency of the distribution system	-	0,92	0,92
The efficiency of the control system	-	0,95	0,95
The total efficiency of the heating system	-	0,8036	3,67
Annual required heating energy for heating $Q_{H,nd}$ for reference climate data and Algorithm prescribed regime of space use and operation of technical systems - CALCULATION according to HRN EN ISO 13790	kWh/a	172.766,00	172.766,00
Annual required heating energy for heating $Q_{H,nd}$ for actual climate data and actual space use regime and operation of technical systems - CALCULATION according to HRN EN ISO 13790	kWh/a	234.253,00	234.253,00
Annual USEFUL required heating energy for the central heating system (obtained by modelling from the bills)	**kWh/a**	**191.363,72**	**191.363,72**
Correction coefficient ($Q_{H,nd\text{-}model}/Q_{H,nd\text{-}proračun}$)	-	0,82	0,82
Annual delivered fuel energy for space heating	**kWh/a**	**238.120,31**	**52.131,34**
Annual delivered fuel energy for space heating	unit/a	23.733,00	52.131,34
The annual cost of fuel for space heating without VAT	**kn/a**	**67.792,85**	**45.875,58**
Direct CO_2 emissions into the environment - space heating	t/a	71,33	12,24
The energy source for cooling	-	Electricity	Electricity
Unit	-	kWh	kWh
CO_2 emission coefficient for energy source used for cooling	kg CO_2/MWh	234,81	234,81
The unit cost of energy source for cooling without VAT	kn/kWh	0,8800	0,8800
The seasonal energy efficiency ratio, SEER	-	2,28	4,8
Annual required heating energy for cooling $Q_{C,nd}$ for reference climate data and Algorithm prescribed regime of space use and operation of technical systems - CALCULATION according to HRN EN ISO 13790	kWh/a	38.380,00	38.380,00
Annual required heating energy for cooling $Q_{C,nd}$ for actual climate data and actual space use regime and operation of technical systems - CALCULATION according to HRN EN ISO 13790	**kWh/a**	**38.380,00**	**38.380,00**
Annual delivered fuel energy for space cooling	**kWh/a**	**16.833,33**	**7.995,83**
Annual cost of fuel for space cooling without VAT	**kn/a**	**14.813,33**	**7.036,33**
Direct CO_2 emissions into the environment - space cooling	t/a	3,95	1,88
The total annual cost of fuel for space heating and cooling without VAT	kn/a	82.606,19	52.911,91

Direct CO_2 emissions into the environment - space heating and cooling	t/a	75,29	14,12

Table 15 - Achieved savings and payback period with the proposed seawater/water heat pump installation measure

ANNUAL SAVINGS		The current state of the building envelope
		Seawater/water heat pump
Total annual fuel cost savings for space heating and cooling without VAT	kn/a	29.694,27
Annual reduction of CO_2 emissions	t/a	61,17
Investment cost without VAT - a mechanical part	kn	795.000,00
Simple payback period - a mechanical part	**year**	**26,8**

3.2. SDEWES Centre

Prefeasibility study is carried out by analysing available data regarding the construction, energy consumption and location parameters. Due to data limitations and lack of reliable data, a prefeasibility study is carried out using various estimations. It should be emphasized that the calculated values given in this section could only be used as indicative references for the rough evaluation of considered technology potential. To obtain real values and propose system capacity and other relevant technical data, in-depth analysis with the on-site visit is necessary.

Methodology

To carry out a prefeasibility study for seawater heat pumps at selected pilot area following methodology and workflow was used. Figure 55 gives a schematic overview of the used approach and methodology for this prefeasibility study.

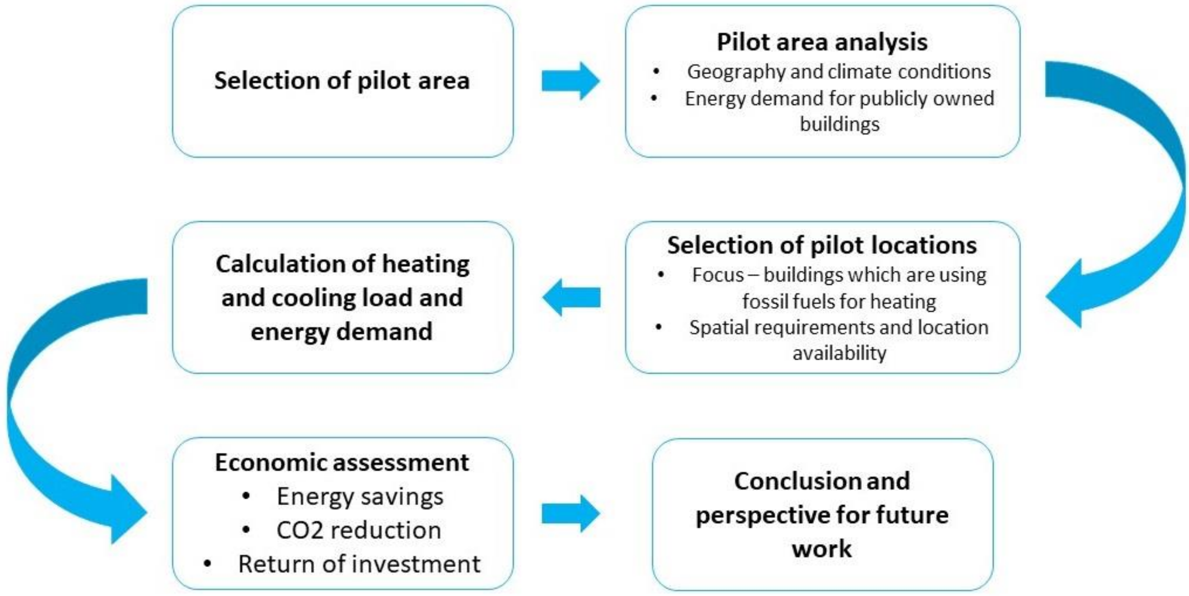

Figure 55 - Methodology used in this prefeasibility study

3.2.1.Seawater heat pumps potential assessment

Construction and energy data are collected and summarized in Table 16. The last column related to specific energy consumption is calculated using annual fuel and energy consumption per square meter of useful surface and per cubic meter of heating volume. For the case of OŠ Frane Petrića, specific energy consumption is around 30 kWh/m^2, or 7.37 kWh/m^3. These values are satisfactory and in line with national standards for energy efficiency. It must be highlighted that object recently went under complete renovation intending to increase energy efficiency, and as a result energy class is upgraded from C to A+, with annual energy savings of approximately 56%. The refurbishment consisted of applying thermal insulation to exposed walls and roofs, the substitution of windows and doors, installation of a solar thermal system for hot water preparation and implementation of regulatory valves on heat exchangers [15].

Table 16 - Summary of construction and energy parameters for considered building

Building	Useful area	Heating volume	Final energy consumption	Fuel consumption	Specific consumption
Unit	A_k [m^2]	V_h [m^3]	$Q_{H,nd,ref,}$ [kWh/a]		[kWh/m^2]
					[kWh/m^3]
OŠ Frane Petrića – Cres	5 990	24 060	177 312	19 397 l (heating oil)	29.60
					7.37
Odgojni dom – Mali Lošinj	877 +	2 743	143 475	10 501 kg (LPG)	146.75
					52.31

	100				
Dom za starije osobe Marko A. Stuparić-Cres	470	n.a.	166 936	15 038 kg (LPG)	355.18
					n.a.

The second considered building is a pupil's dormitory which uses LPG to satisfy heating needs. Since the building is built at the beginning of the 20th century without recent renovation works which would enhance the energy efficiency, specific consumption is notably high with 146 kWh/m^2 and 52.3 kWh/m^3. Dom za starije osobe Marko A. Stuparić-Cres, as already mentioned, has a high specific energy consumption of 355.18 kWh/m^2, and Figure 56 illustrates the average monthly final energy consumption.

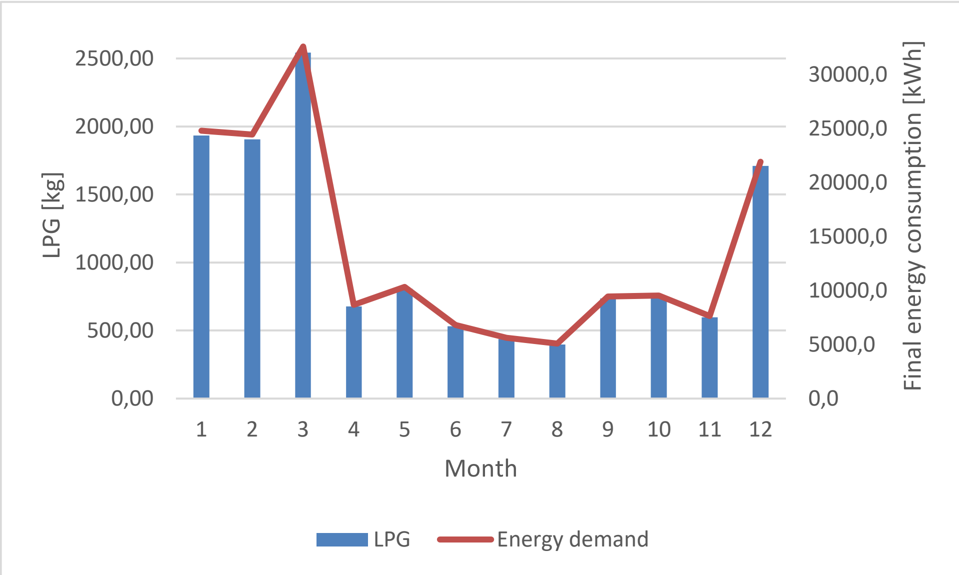

Figure 56 - Average LPG consumption and provide energy in the 5 years - Dom za starije osobe Marko A. Stuparić

3.2.2.Results analysis and interpretation

In the previous subsection, specific energy consumption is calculated for the final energy consumption, which differentiates from real heat demand and provided heating energy. Since the heating boilers are working with an efficiency below theoretical 100%, this consumption from Table 17 should be multiplied by the boiler efficiency to get annually provided heating energy used in the considered object. For the oil boilers, efficiency varies between 60% for old systems to 85% for non-condensing boilers. A new condensing boiler has an even higher efficiency of about 92%, but they are not used in the presented cases. Since the precise value regarding the boiler efficiency cannot be determined, especially for such a system that is already used for longer periods, we estimated the average value of 80%. For the case of the dormitory where LPG is used as a fuel in condensing boiler (Weishaupt, WG 20F/1-C), efficiency is estimated to be 90% to calculate final heat demand. The same 90% is estimated for Dom za starije osobe Marko A. Stuparić-Cres as well.

Table 17 - Calculated heat demand for considered objects

Building	Final energy consumption	Boiler efficiency	Heat demand	Specific consumption
Unit	**$Q_{H,nd,ref,}$ [kWh/a]**	**[-]**	**kWh/a**	**[kWh/m²]**
				[kWh/m³]
OŠ Frane Petrića – Cres	177 312	80%	141 849	23.7
				5.9
Odgojni dom – Mali Lošinj	143 475	90%	129 127	132.1
				47.1
Dom za starije osobe Marko A. Stuparić-Cres	166 936	90%	150 243	355.2
				n.a.

When the annual heat demand is known, alongside the specific consumption, it is possible to estimate the required seawater heat pump capacity and annual electric demand for its operation. Seawater heat pumps have high COP up to 7 when used for heating, while the Energy efficiency ratio (EER) can be even higher for cooling purposes [8]. Nevertheless, since actual data for calculating heat and cooling load and annual energy demand are not available, in this study, we assumed the conservative COP of 4 while calculating electric demand as a safety margin. Furthermore, since the electric heaters are mainly used for hot water preparation, in the case of switching to seawater heat pumps, this additional demand should be considered. To select the appropriate size of the installed system, months with peak consumption are specially analysed to ensure that peak loads can be covered with a new system. Figure 57 illustrates the hourly heat load curve for typical winter months on the archipelago. The curve is designed using outdoor temperatures and referent and unidimensional parameters for the considered period, which refers to heat consumption.

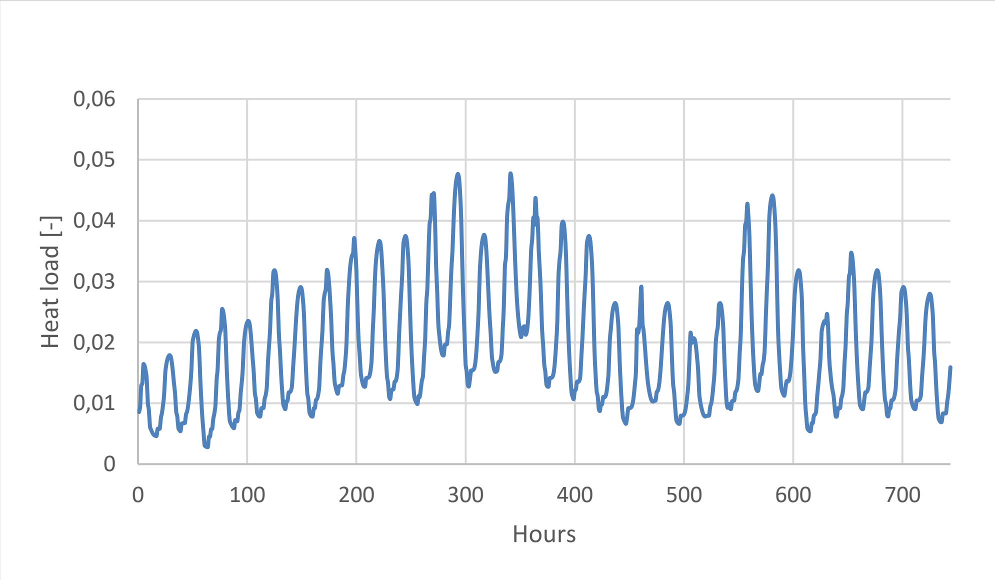

Figure 57 - Hourly heat load for a typical winter month

Calculation of required system capacity

In this section, a simplified method for estimating the required nominal capacity of seawater heat pumps is given. Equation 1 shows how the required electric demand was obtained using heat demands from Table 9 and an estimated COP of 4.

$$Q_{el} = \frac{Heat\ demand\ (kWh)}{COP}\ [kWh] \tag{1}$$

To calculate the average capacity of the installed system, which is used during the one month, it was necessary to use the heating load curve from Figure 57. Previously calculated heat demand for winter months is distributed using the heating load curve to see where the peak values occur. This is important when considering the capacity of the heating system since the installed unit must satisfy demand at every point.

Table 18 presents the electricity consumption required for seawater heat pump operation to satisfy heating demand.

Table 18 - Total and monthly electric demand for heating [kWh]

	OŠ Frane Petrić	Odgojni dom Mali Lošinj	Dom za starije osobe Marko A. Stuparić-Cres
1	6926.4	5769.0	5578.0
2	5513.4	6634.4	5449.6

3	4100.2	5771.7	7332.4
4	2800.0	-	1954.5
5	2291.6	-	2324.9
6	1185.2	-	1535.7
7	1200.0	-	1264.6
8	1360.2	-	1145.1
9	1185.2	-	2124.1
10	1200.0	6922.8	2144.9
11	2630.8	1992.0	1722.6
12	4665.6	5771.7	4934.2
Total	**35 062.6**	**32 281.9**	**37 560.8**

For the case of OŠ Frane Petrića, peak consumption is in January, with a peak load of about **93 kW**. In the case of Odgojni dom, Mali Lošinj required peak load is for February and it also accounts for the required seawater heat pump capacity of **93 kW**. The third considered building has a peak load of **74.5 kW** calculated for February.

3.2.3. Overall description of the application

Since the buildings don't have an installed cooling system, there is no potential for energy savings in this part. Nevertheless, since the archipelago has Mediterranean climate conditions, the energy required for cooling cannot be neglected. Even more, this parameter can significantly improve the return of investment and system economics, since higher load capacities are achieved, and no additional investments are required since the heat pumps can satisfy both needs. For this reason, cooling demand was estimated for each building using national referent values for similar cases and then later used in economic assessment. For the location of Split, cooling demand is estimated to be around 50 kWh/m^2 [16]. Since the solar gains are a little bit lower in the case of the Cres-Lošinj archipelago, this value was reduced to 40 kWh/m^2 and then multiplied by the useful building area. Table 19 presents obtained values for considered buildings. The high cooling load for OŠ Frane Petrića is highly questionable since the school is mostly not used during the summer, implying that the cooling needs are significantly lower. Obtained values are only indicative since the actual cooling load was not calculated. Nevertheless, they can be used for economic assessment to calculate additional electric demand.

Table 19 - Estimated cooling demand for considered buildings

Building	Useful area [m^2]	Cooling demand [kWh]	Electric demand [kWh]
OŠ Frane Petrića – Cres	5 990	239 600	79 866
Odgojni dom – Mali Lošinj	977	39 106	13 035
Dom za starije osobe Marko A. Stuparić-Cres	470	18 800	6 266

3.2.4.Economic assessment

The economic assessment was carried out using two approaches. In the first one, cashflow is calculated only for the replacement of heating fuels used as an energy source, while the second one considered additional costs for the cooling system as well. For the second approach, it should be highlighted that cooling causes additional operating costs, while there is not possible to determine potential savings since there is no central cooling system installed in considered buildings. Furthermore, cooling demand is calculated using a specific national value for cooling load per square meter, while the actual demand might differ significantly.

To calculate cash flow for each building following approach was used:

- Investment costs and electricity demand for seawater operation represent expenses
- Savings in used fossil fuels represent "income"
- In the case of heating, various COP (3, 4, 5.5) are used as a sensitive analysis
- In the case of cooling, heating COP was maintained at a 4, while cooling EER was varied between 6, 7 and 12 for the best-case scenario which is noticed for some installations
- Specific investment for seawater heat pumps 0.48 €/W [17]; exchange rate Euro-Croatian Kuna (HRK) 1€=7.56 HRK
- Fuel prices from December 2019 collected from bills; electricity prices for the residential sector from national electricity supplier (Hrvatska elektroprivreda - HEP d.o.o.) web pages
    - LPG 4.88 HRK/kg
    - Heating oil 4.07 HRK/l
    - Electricity 0.77 HRK/kWh
- A specific division of investment costs for device installation, which were not taken into calculation individually, since they are covered in the previously mentioned specific investment of 0.48 €/W is the following:
    - Seawater heat pump accounts for about 30-40% of total costs;
    - Pipe connection costs vary between 15-25%;
    - Other costs (including drilling) are between 40-50%

  It should be emphasized that the share of costs might vary significantly depending on the technology and construction requirements. The bottom one is especially variable since they are related to location specifics, and they include drilling works, boiler room, pipeline length and similar. If the considered object is not near the sea and wells are needed for water intake, these costs might be dramatically higher depending on the soil composition and required depth.

- Costs of heat exchangers and other parts of HVAC systems are not considered here in the prefeasibility study since the complete information about the existing system is unknown, and even more, to make an appropriate design of the system heat/cool loads need to be calculated for each room, individually, using national and international standards (HRN EN ISO 12831, HRN EN ISO 13790, and VDI 2078). Estimated specific prices are as follows [16]:
    - Radiators 100-150 kn/m^2
    - Underfloor heating 130-175 kn/m^2
    - Ceiling heating ~300 kn/m^2

- Fan coils 150-220 kn/m^2

- The initial price of the fixed part of the concession price is calculated by the occupied area in square meters and it is defined in the Decree. Nevertheless, the final price is often negotiated with the relevant public authority directly or determined based on collected offers on public tenders. In the case of seawater heat pumps, the concession price is often symbolic.

1st scenario – Replacement of heating source

For the case of Dom za starije osobe Marko A. Stuparić-Cres, if the LPG is substituted with seawater heat pumps, the return of investment is achieved in 8 years, with an average COP of 3. If the COP is higher, as expected for seawater heat pumps, the period of return of investment is decreased to 6 years for both cases. Results of the economic assessment are given in Figure 58.

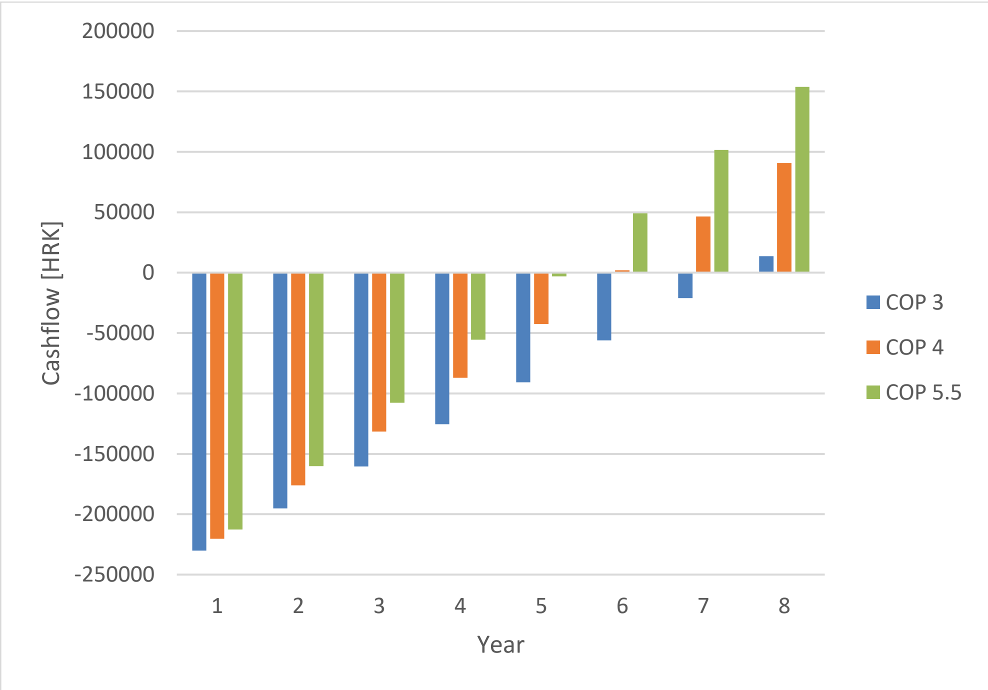

Figure 58 - Cashflow for the case of Dom za starije osobe Marko A. Stuparić-Cres

Odgojni dom Mali Lošinj - Učenički V dom has a longer period for return of investment. For the referent case where COP is 3, the payback period is 19 years. If the COP is increased to 4 and 5.5, payback time is reduced to 13 and 11 years, respectively. Results are summarised in Figure 59.

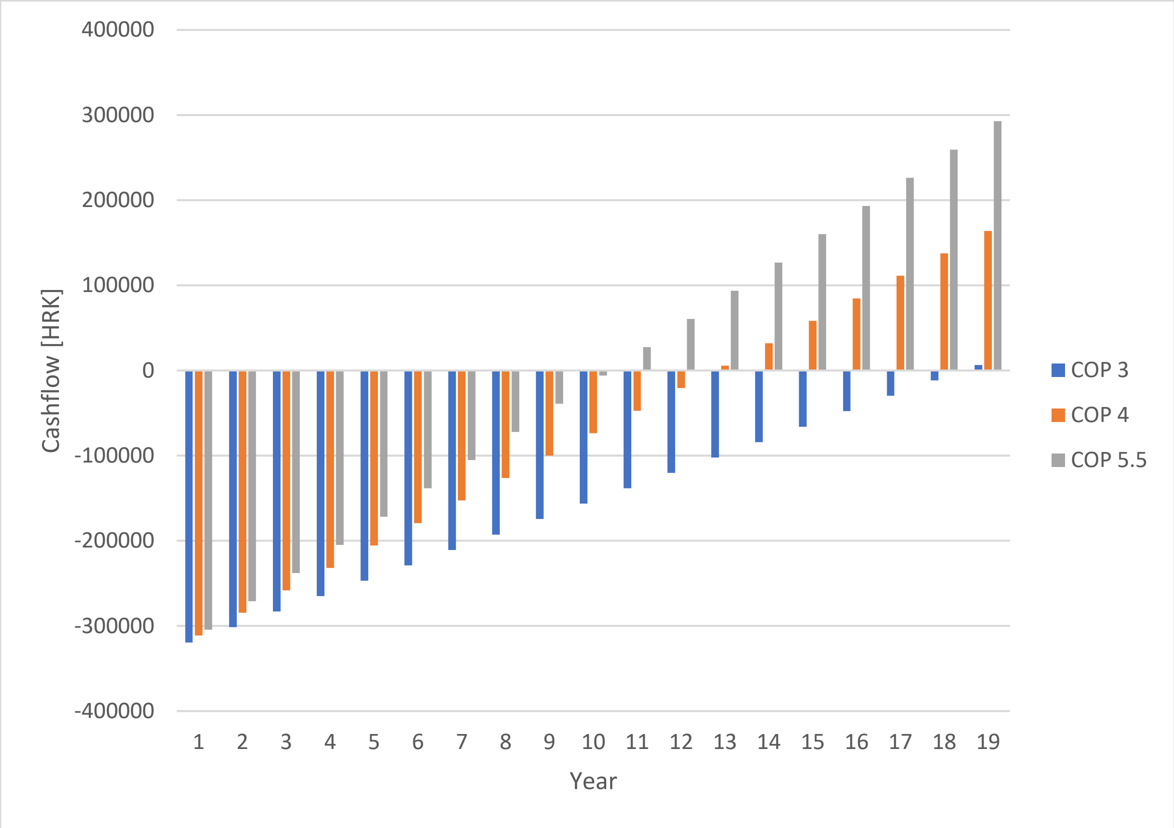

Figure 59 - Cashflow for the case of Odgojni dom Mali Lošinj - Učenički V dom

Osnovna škola Frane Petrića Cres has a similar payback dynamic as the object analysed in Figure 58. If the COP is 3, the return of investment is achieved after 8 years. With the further increment of COP to 4 and 5.5, payback time is reduced to 7 and 6 years, respectively. Figure 60 illustrates the cashflow for elementary schools.

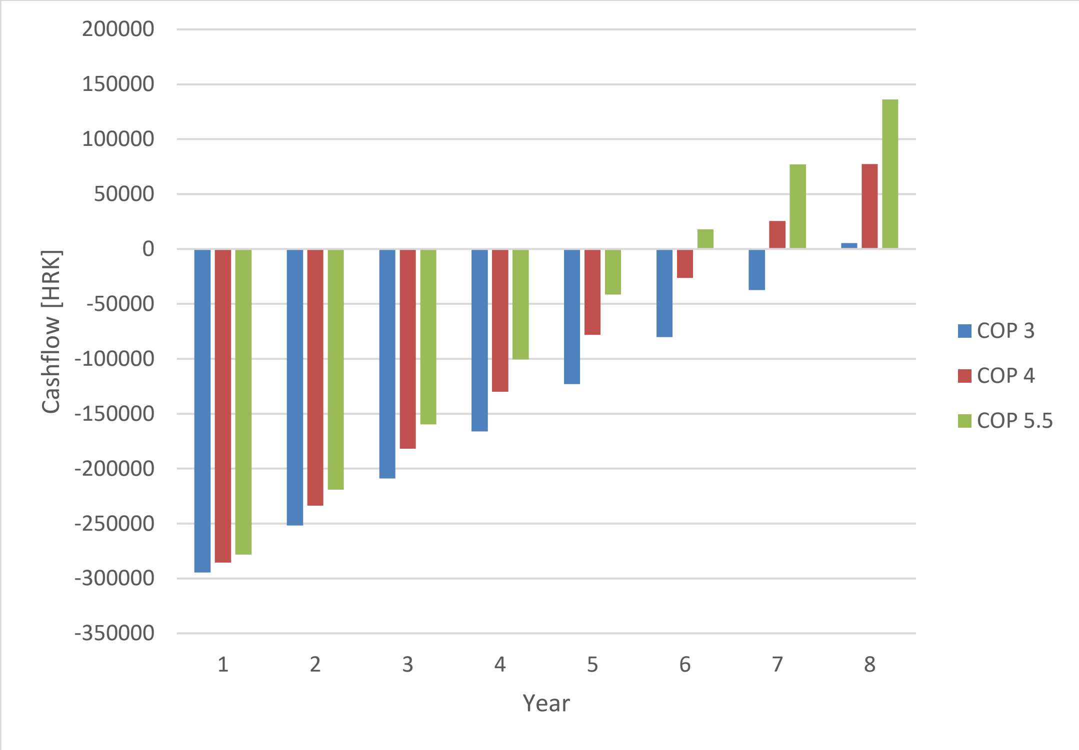

Figure 60 - Cashflow for the case of Osnovna škola Frane Petrića, Cres

2nd scenario – Inclusion of additional cooling demand

When the cooling demand and its costs are considered for economics, the return of investment is slightly prolonged due to the reasons explained above. To mitigate this effect when cooling represents additional expenses, COP for heating was held at 4 for all considered scenarios, while cooling EER was varied between 6, 7, and 12 for the best-case scenario.

In the case of the Dom za starije osobe Marko A. Stuparić-Cres, the return of investment is for all cases achieved after 7 years. This is the same period as in the previous scenario when COP for heating is 4, implying that cooling demand for this building has a lower impact on the return of investment. Results are presented in Figure 61.

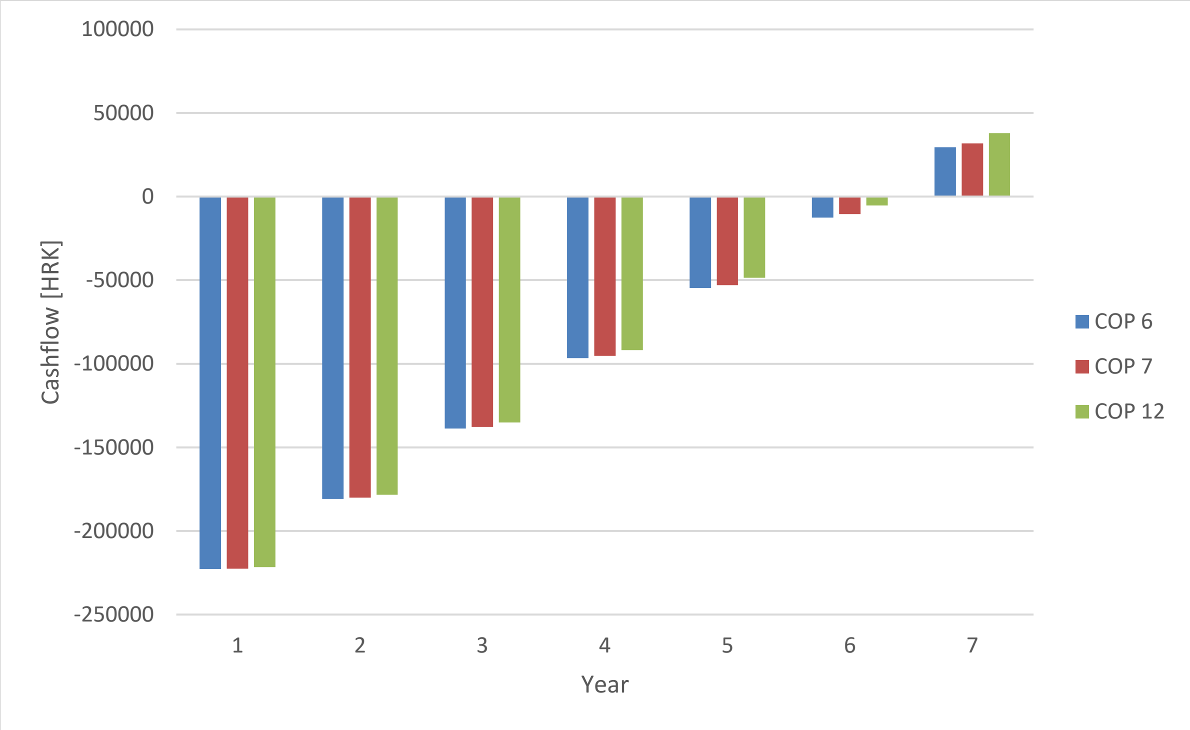

Figure 61 - Cashflow for the case of Dom za starije osobe Marko A. Stuparić-Cres (cooling included)

Odgojni dom Mali Lošinj has the return of investment in 16 years for cases when the EER for cooling is 6 or 7. In case EER is further increased to 12, the return of investment is achieved after 15 years. Figure 62 gives detailed results for economic assessment with the inclusion of cooling needs. Compared to the 1st scenario where only heating is considered, the payback period is prolonged for at least 3 years (depending on cooling EER), implying that cooling demand has an important role while considering a potential investment. Nevertheless, high EER has a very low influence on return of investment since its increment to 12, reduced the payback period only for one year.

Finally, the most significant impact of cooling mode is visible for the elementary school (Figure 63). Even though, it should be emphasized that due to huge useful area, and calculation method where specific cooling demand is used, obtained cooling load and annual energy demand does not represent the actual situation. Even more, since the building is completely renovated, specific cooling consumption is probably significantly lower, which would result in a faster return of investment. In the case of cooling EER is 6, the payback period is after 16 years. If the average cooling EER is increased to 7, the payback time is 14 years. Compared to the referent case, this is for about 7 years longer. Finally, the best-case scenario with an EER of 12 has a complete return of investment after 10 years. Nevertheless, thermal comfort is greatly increased if the cooling system is installed as well. Also, it should be considered fact that school is not used during the summer period when there is a cooling need; therefore, this heat pump feature might not be needed at all. In such a case, the 1st scenario, where only savings in heating mode are considered gives better insight into cash flow for this building.

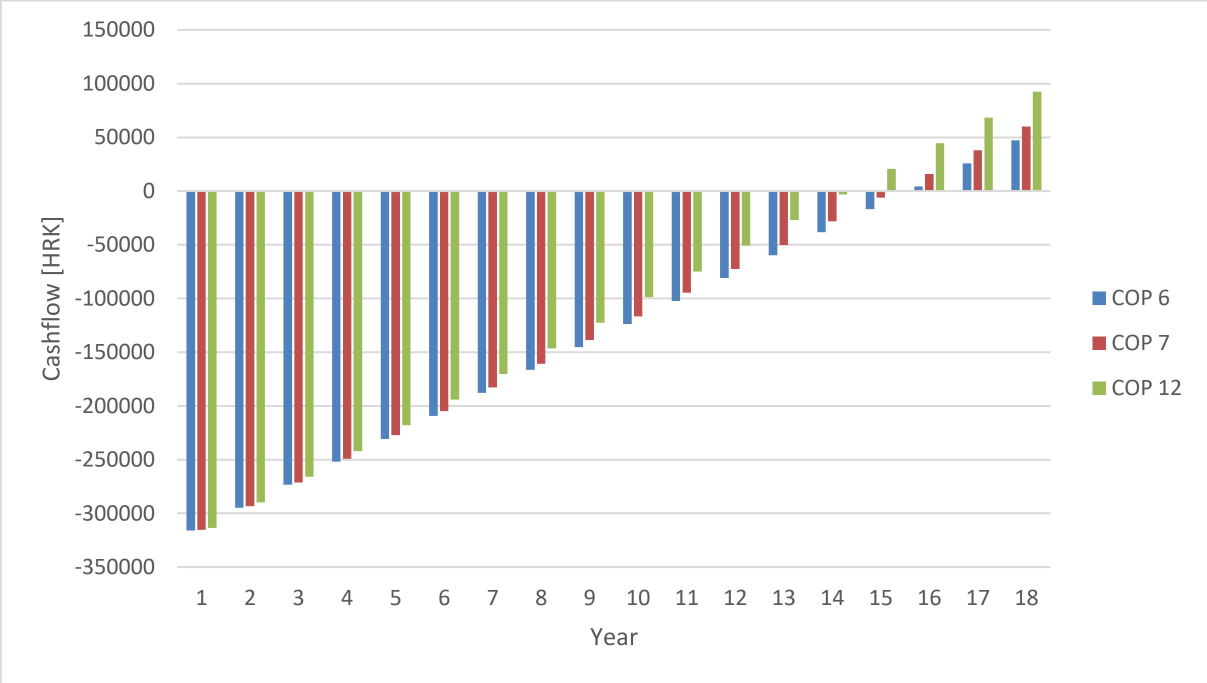

Figure 62 - Cashflow for the case of Odgojni dom Mali Lošinj - Učenički V dom (cooling included)

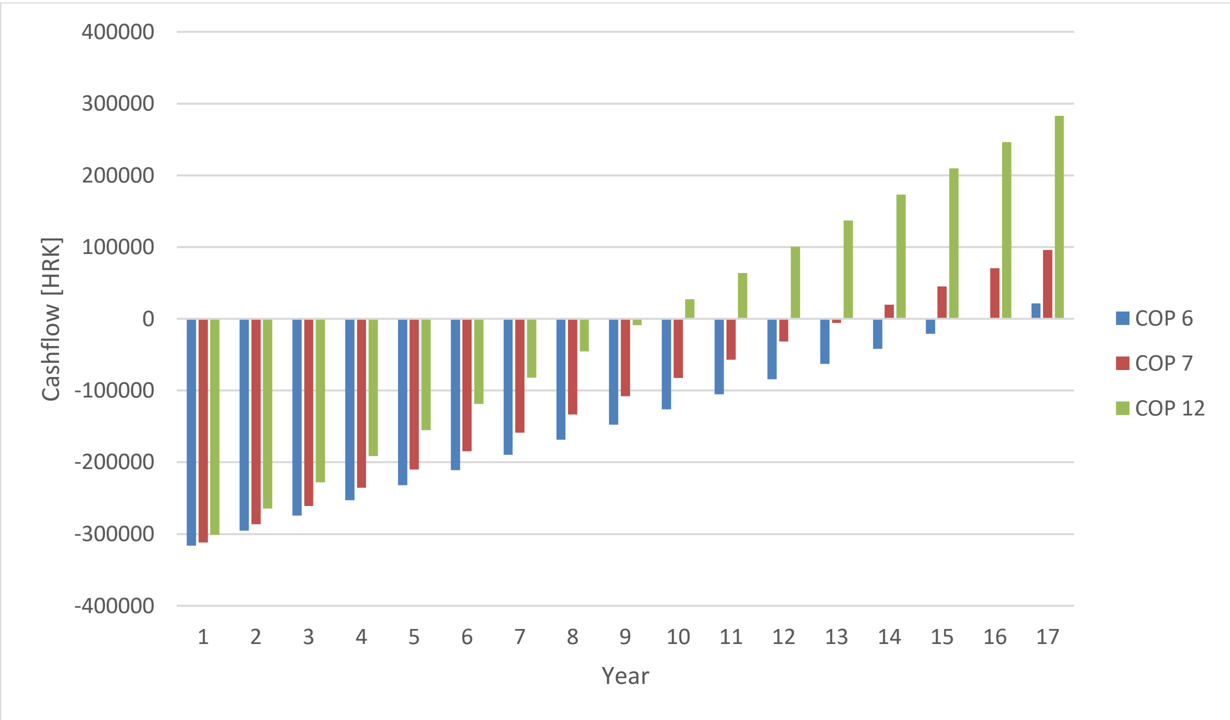

Figure 63 - Cashflow for the case of Osnovna škola Frane Petrića, Cres (cooling included)

Savings in fossil fuels and CO_2 emissions

Savings in the consumption of fossil fuels are the critical parameter when considering the deployment of renewable energy sources. Savings in fuel consumption are directly related to cash flow since they represent the main operational costs. Besides, decarbonisation and energy transition requires the abandonment of fossil fuels and the usage of clean and renewable energy sources. Figure 64 presents the savings in fossil fuel consumption for each considered building. In total, around 19 397 litres of heating oil, and around 25 500 kg of LPG could be saved on an annual basis if the seawater heat pumps are deployed for heating needs.

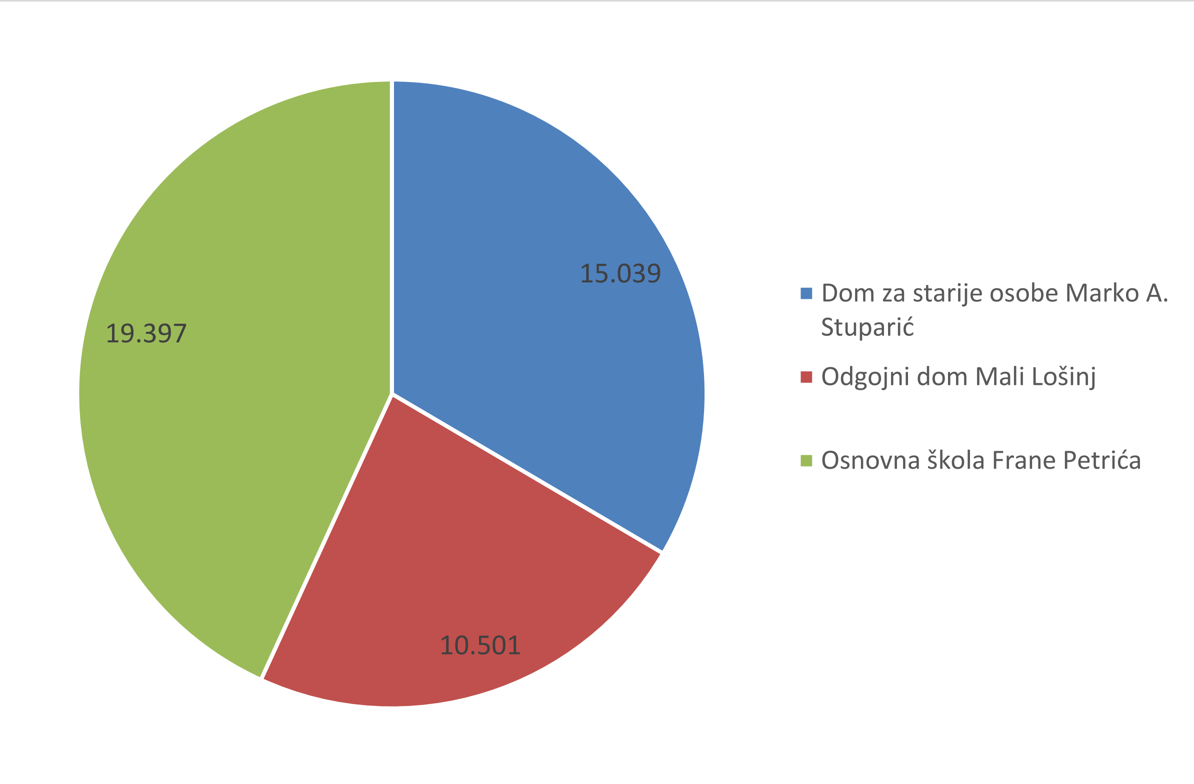

Figure 64 - Savings in fossil fuel consumption

When it comes to savings in CO_2 emissions, it is evident that the deployment of seawater heat pumps can significantly reduce CO_2 emissions compared to the usage of fossil fuels, even when the electricity mix is not 100% renewable. When calculating potential savings, used COP and EER were 4 and 6, for heating and cooling, respectively. In total, more than 100 000 kg of CO_2 could be mitigated on an annual basis if the heating is based on seawater heat pumps, instead of fossil fuels boilers. Figure 65 presents the CO_2 emissions for each considered building with their referent case where fossil fuels are used, and emissions if the seawater heat pumps are deployed.

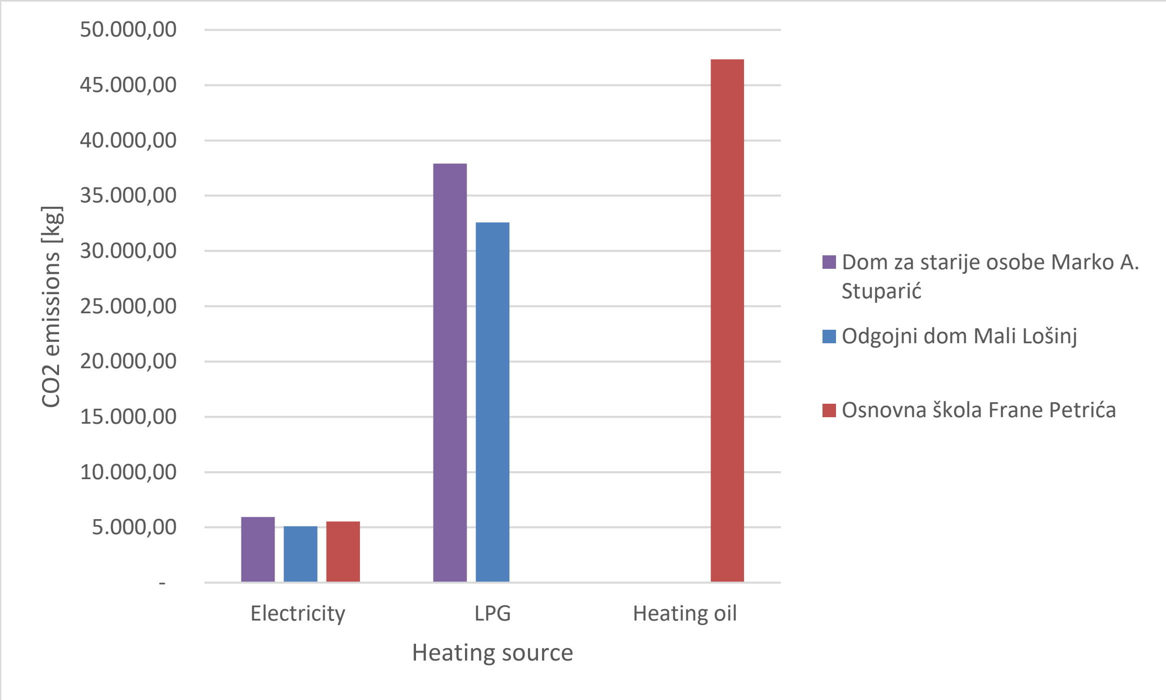

Figure 65 - CO_2 emissions for referent cases and seawater heat pumps

If additional carbon emissions from cooling needs are considered as well, savings are lower for about 24 000 kg yearly, and in this case, are slightly above 76 800 kg per year.

3.2.5.Multicriteria analysis for considered objects

In this subsection, a brief overview regarding the potential for installation of seawater heat pumps is given considering the system and location requirements and specifics. Besides, we proposed the available heat pumps models applicable for considered objects.

Dom za starije osobe Marko A. Stuparić-Cres

This building has a high specific heat demand (355.18 kWh/m^2) due to very bad conditions of the building envelope which seeks refurbishment. This problem is even more evident since the LPG is used as a heating source, raising distribution and environmental concerns. Nevertheless, this building is located near the sea which offers a great opportunity for the deployment of seawater heat pumps and complete decarbonisation of the heating system. Even more, the installation of heat pumps offers an opportunity for the central cooling system as well, which can significantly enhance the thermal comfort during the whole year, especially important for such objects.

The heating peak load is around 74.5 kW (for spatial heating), while additional demand for hot water preparation is not calculated but should be considered before the installation of a designed system. As it was already mentioned, a building needs complete refurbishment and thermal insulation which will result in dramatically lower thermal load and savings in annual energy consumption. Besides, if the HVAC system is considered for installation, additional works on distribution networks inside the buildings are necessary, and they include the deployment of fan coils or underfloor/ceiling heating systems to achieve optimal thermal comfort and system performance. Return of investment for the installed system is achieved after 7 years, even though it needs to be emphasized that additional investment costs in equipment and construction works would prolong this period for a few years longer.

Odgojni dom Mali Lošinj - Učenički V dom

Odgojni dom in Mali Lošinj consists of two buildings where one being a dormitory and the other one being a sports hall. The dormitory is an old building without thermal insulation and with quite poor energy performance since the heating load is around 146 kWh/m^2. The main energy source for heating is LPG without an installed cooling system. The sports hall has installed fan coils with a capacity of 28.5 kW which implies that seawater heat pumps might be an ideal solution for heating and cooling purposes. Nevertheless, in the case of heat pump installation, the building needs significant refurbishment of an outside envelope, but also additional works and investment to substitute currently used heat exchangers (radiators) in the main dormitory object. Now, the required capacity to cover heating peak loads is estimated to be around 93 kW, while a furtherer reduction is expected if renovation works are carried out. The investment payback period is estimated between 11 and 13 years only for heating, while this period is extended to 16 years if cooling is included as well. The object is not located close to the sea which implies the need for intake wells and additional drilling works. This fact can have a pronounced influence on the economic assessment and return of investment.

Osnovna škola Frane Petrića, Cres

In the case of elementary school, due to the recent refurbishment of the building envelope, specific heat consumption is around 30 kWh/m^2, and the building is classified as an A+ in terms of energy efficiency classification. The refurbishment has achieved savings in primary energy consumption by more than 50%, nevertheless, heating oil remained the main energy source for spatial heating. Since the object went under significant enhancement in terms of specific heat consumption, and since fossil fuel is still used as an energy source, seawater heat pumps might be a great substitution, and a key step toward nearly-zero energy building. The required capacity is estimated to be around 93 kW for spatial heating. Hot water preparation is partially covered by solar thermal collectors. Calculated cooling demand in this study is extremely high since it is based on the useful area of the building and not the real demand. Furthermore, since the school is not used during the summer period, cooling demand is significantly lower. Moreover, in this case, the need for such a system is questionable since it significantly influences the investment costs and return of investment. Achieved energy savings and fuel consumption for heating can return the investment after 6 or 7 years, while with additional cooling demand this is prolonged to 14 years in the best-case scenario. Once again, additional costs for the installation of the required distribution system are not considered in this study. Besides, the building location is not near the sea which implies the need for drilling works and wells for water intake. This might have a crucial impact on overall investment costs and project feasibility.

Seawater heat pump models

In this subsection, potential heat pumps which can be used for seawater (brine) are given in Table 20. The prices are obtained from direct contact with the company representative, and they represent the costs for the device and regulation system. The additional cost of 3 000 € for a heat exchanger that can be used for seawater is added to the total price. An additional investment of about 2 000- 2 500 € needs to be considered if the active cooling mode is used as well. Passive cooling is a default option that comes with seawater heat pumps.

Table 20 - Considered seawater heat pumps [18]

Manufacturer	Model	Capacity [kW]	COP/EER [-]	Price [€]
Viessman Vitocal 200-G PRO (temperatures up to 60 °C)	BW 202.A080	Heating/cooling (75.4/59.2)	4.7-5.9	21 170
	BW 202.A100	Heating/cooling (101/79.3)		24 054
Viessman Vitocal 300-G PRO (temperatures up to 60 °C)	BW 302.D090	Heating/cooling (84.8/67.6)	4.7	30 247
Viessman Vitocal 350-G PRO (temperatures up to 65 °C)	BW 352.B076	Heating/cooling (76/58.8)	4.4/up to 5	52 866
	BW 352.B097	Heating/cooling (96.9/74.6)		
	BW 352.B056	Heating/cooling (78.6)		

3.2.6.Analysis of additional buildings

This is the part of the pre-feasibility study of selected pilot locations that were made after the first meeting of the local HUB in Cres-Lošinj Archipelago. Here, the additional potential assessment for the deployment of seawater heat pumps was (SWHP) carried out for two school buildings located in Mali Lošinj and the city hall. The school buildings, elementary and high school, are located side by side and they share the boiler room for heating. Figure 66 presents the locations of considered buildings with their distance to the closest sea point. As can be seen, the closest point in case of direct seawater intake is from the marina, which would require the development of a complicated distribution system since most of the installation would go through the town. The buildings are located approximately 30-40 meters above sea level, which is important information in case wells are considered for brackish or seawater intake.

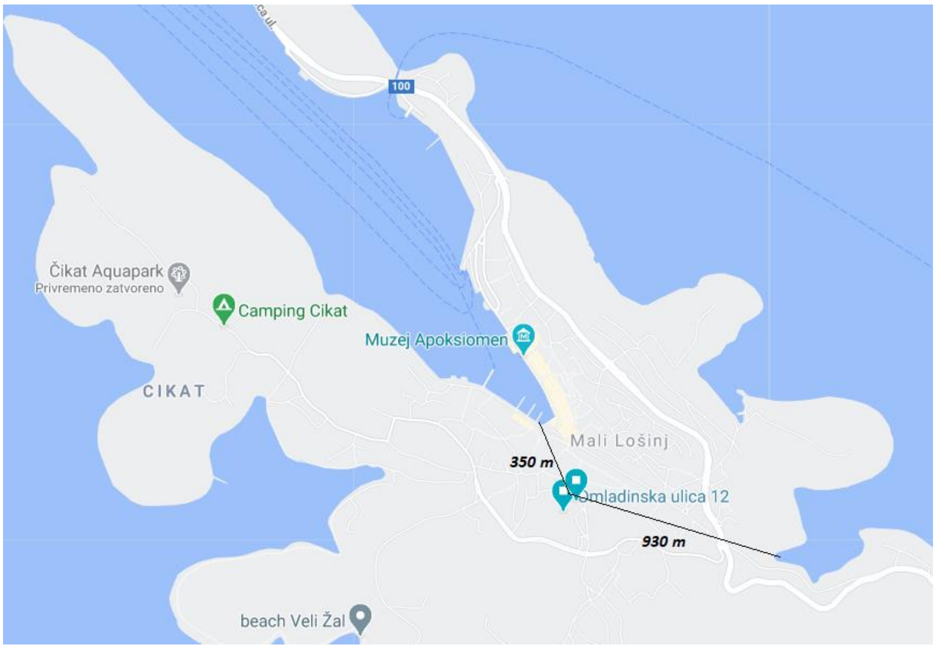

Figure 66 - Location and distance from the sea for two considered buildings

Osnovna škola Maria Martinolića, Mali Lošinj

The first considered building is the elementary school located in the town of Mali Lošinj. The building is relatively new, built-in 2005. It is used during the 250 days, five days per week, for about 12 hours per day. The number of users is approximately 580. In 2014, the energy audit is made with a detailed description of the building construction characteristics. Furthermore, the annual energy demand is calculated considering all physical, climate and technical parameters using the HRN EN 13790:2008 standard. Provided values regarding the heat demand monthly are used to design the potential capacity of SWHP that would satisfy the required demand. The additional, simplified economic assessment is carried out comparing the expenses of the current system and potential savings that may arise from the deployment of SWHP. Construction parameters are summarised in Table 21.

Table 21 - Construction parameters of the considered elementary school building

Data	Unit
The heating surface of the building	8 531.44 m^2
The heating volume of the building	19 124.27 m^3
Useful surface	4 308.00 m^2
Facade area	6 021.81 m^2
Glazing area	1 164.96 m^2

Currently, school is using heating oil as the energy source for heating with an approximate consumption of about 19 000 litres per year. This provides around 193 900 kWh of thermal energy, of which 156 790 kWh is given to aluminium radiators with an installed capacity of 285 kW, and an additional 4 188 kW is used for sanitary hot water. Furthermore, two pressure chambers, with electric heaters of 115 and 58 kW are used for heating and ventilation of the main and dining hall. Altogether, all heating bodies have an installed capacity of about 520 kW. In a separate boiler room, there are two heating boilers with an installed capacity of 800 kW, each. Measures proposed to enhance the energy class of the building could provide 4 918 kWh/a of savings, which is not economically viable since the required costs for this would be almost 500 000 HRK. This is since thermal coefficients are slightly above proscribed ones, and the potential for savings is slightly reduced. Even though, reconstruction of glazing areas with Aluminium and wooden frames could be considered due to lower investment costs and to enhance thermal comfort of the building.

The internal temperature for the heating period is set at 20 °C, and it is estimated that there are 131.5 heating days in a heating season. The internal temperature for the cooling season is 26 °C, with peaks during the summer periods when the building is mainly not used. Seasonal thermal losses are 376 334 kWh during the November-March period which is considered as the heating season. Simultaneously, seasonal heating gains are approximately 179 000 kWh. Calculated seasonal heating and cooling demands are given in Table 22.

Table 22 - Heating and cooling demand through the year for considered elementary school building

Month	Heating demand	Cooling demand
January	58 668	-
February	38 729	215
March	25 945	1 068
April	7 416	3 189
May	217	8 376
June	-	20 708
July	-	36 412
August	-	33 477
September	-	15 202
October	970	4 451
November	20 210	198
December	51 900	161
Total	**204 055**	**123 457**

From Table 22 the highest energy demand occurs in January, while the highest cooling demand is in July. Since the cooling demand is highest in July and August, when the building is not even used, the required system capacity was estimated by considering only the heating demand. The heating load distribution curve is built using the hourly external temperatures for the sharpest winter month when the heating load is highest. Monthly heat demand of 58 668 kWh is distributed over the curve and the detected peak is used as the system required capacity. In the case of elementary school, this value is 198.3016 kW, which brings us to at least the required capacity of **200 kW** for a seawater heat pump.

Srednja škola Ambroza Haračića Mali Lošinj

The second considered building is the high school built in 1975. The building consists of the ground floor and one floor, with about 21 classes and 50 workers. In 2016, a detailed energy audit is carried out using the available consumption data from 2015. Once again, using the HRN ISO 13790:2008 standard, annual, and monthly heating and cooling demand is calculated. Table 23 summarise the main building characteristics.

Table 23 - Construction parameters of considered high school building

Data	Unit
The heating surface of the building	5 560.70 m^2
The heating volume of the building	9 043.77 m^3
Useful surface	2 199.34 m^2
Facade area	3 669.26 m^2
Glazing area	590.50 m^2

As the heating source, the school is using heating boilers located in a separate boilers room with an approximate annual consumption of 10 900 litres. This provides around 111 400 kWh of thermal energy which is given to aluminium and iron radiators (27 pieces) of installed capacity of 74 kW. Installed capacities of heating boilers are 800 and 380 kW. Simultaneously, the building does not have a central cooling system but there are 13 split system devices with an installed capacity of about 75 kW, with an annual consumption of 3 667 kWh. The sanitary hot water preparation is carried out by the usage of separate in-situ electric boilers. Thermal insulation of the building envelope is necessary since the building was not renovated after being built. The potential for energy savings, in this case, is around 19 415 kWh on annual basis with an investment cost of 110 00 HRK and a payback period of seven and a half years.

The internal temperature for a heating period is set at 20 °C, and it is estimated that there are 131.5 heating days in a heating season in case the initial temperature for turning on heating is 12 °C. The internal temperature for the cooling season is 24 °C, with peaks during the summer periods when the building is mainly not used. Annual thermal losses are 439 792 kWh, mainly during the November-March period which is considered as the heating season. Simultaneously, annual heating gains are approximately 409 653 kWh, with peaks during the summer periods, when the building is not even used. Calculated seasonal heating and cooling demands are given in Table 24.

Table 24 - Heating and cooling demand through the year in case of a high school building

Month	Heating demand	Cooling demand
January	37 825	1 353
February	22 838	2 926
March	15 093	5 557
April	5 095	10 032
May	-	16 170
June	-	24 244

July	-	31 283
August	-	29 526
September	-	16 268
October	988	9 951
November	11 725	2 927
December	33 959	1 152
Total	**127 522**	**151 388**

As it can be seen from Table 24, the highest heating demand is in January (37 825 kWh), while the highest cooling demand is in July (31 283 kWh). Similar to in the case of elementary school, heating demand from January is extrapolated over the distribution curve for winter month and the required capacity to satisfy the peaks in demand should be 127.8509 kW, which is rounded to **130 kW**.

City hall of Mali Lošinj

One of the buildings that should be considered for the installation of the SWHP is the town hall that is placed next to the sea, which can be seen in the figure below. There is data for the energy consumption from 2009 to 201 which is obtained from the energy audit made in 2012.

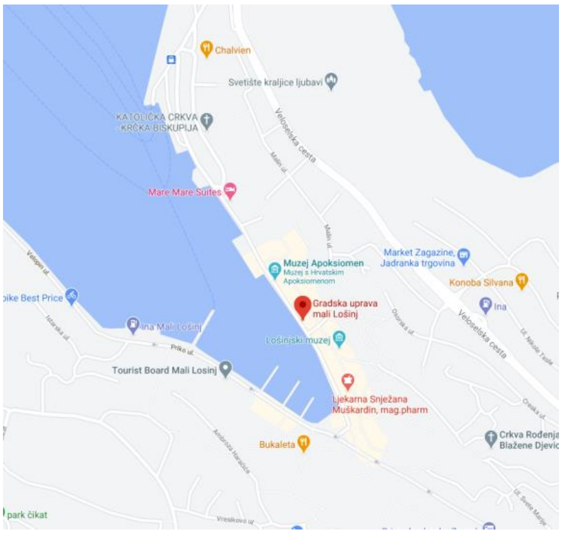

Figure 67 - Location of the City hall

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Figure 68 - City hall of Mali Lošinj

For heating is used fuel oil, while part of the electric energy is used for the air conditioning during the summer. Additional data can be seen in the tables below.

Table 25 - Data on energy consumption

Energy consumption	2009	2010	2011
Electric energy [kWh]	58.487	57.847	60.886
Fuel oil [l]	4.000	14.000	10.000

Table 26 - Data on energy consumption

CO_2 emissions [kg/year]	2009	2010	2011
Electric energy	21.991	21.750	22.893
Fuel oil	10.589	37.062	26.473

Estimation was made that the installation of the SWHP would cost 420.000 HRK with yearly savings of 38.537,59 HRK. More detailed information is given in the table below.

Table 27 - Costs and savings after the installation of the SWHP

Data	Unit
Energy savings [kWh/year]	71.816
Investment cost [HRK]	38.537,59
Yearly savings [HRK/year]	420.000,00
Simple payback period [year]	10,9
Reduction of CO_2 [tCO_2/year]	21.978

Economic assessment for schools

The economic assessment was carried out by comparing the existing system and SWHP as an alternative technology. Investment costs were calculated by considering system nominal capacity and specific investment cost for SWHP of 0.48 €/W. The exact investment costs might vary significantly, which strongly depends on the design system parameters, necessary construction works, need for developing distribution system and similar. Operating costs are related to electricity consumption for the operation of SWHP for heating and cooling, and they are calculated with an average electricity price for 2019, which was 0.77 HRK/kWh. Potential savings are related to savings in consumption of heating oil, which is completely substituted by the introduction of SWHP. These three parameters are considered in cashflow for economic assessment and calculating the payback period. Figure 69 and Figure 70 represent the payback periods in a case when SWHP are deployed only for heating (Figure 69) and in case they are used for heating and cooling (Figure 70), simultaneously.

Currently, the cooling demand of 22 220 kWh per year is satisfied by 20 split systems of installed capacity of 101 kW. The cooling demand is calculated from the nominal installed capacity and average working annual working hours of devices which were 220. Installed electric capacity for split systems is 40 kW, which brings to us an average EER of 2.53, which is expected in the case of such devices. In case the SWHP is deployed for cooling as well, savings on electric consumption could be up to 6 000 HRK per year.

As can be seen, the payback period is strongly influenced by the Coefficient of performance (COP) in the case of heating and energy efficiency ratio (EER) in the case of cooling. In case, heat pumps are considered only for heating, the payback period varies between 15 and 20 years, depending on the COP. When the cooling is considered as well, the payback period is 17 years, for two considered EER 6 and 8, and 14 years in the case that SWHP has EER 12. While calculating the payback period for heating and cooling, it is assumed that HP is operating with an average COP for heating of 4.5.

Second, the considered building has a lower heating load and annual energy consumption, therefore it is expected that the payback period would be prolonged. Figure 71 and Figure 72 presents the cashflows for high school. As can be seen, the payback period is extended for approximately three years in case of all considered COP. In case the COP is 5 or lower, the return of investment is achieved after at least 20 years, while COP of 5.5 reduces the return of investment to 18 years. Figure 72 illustrates the cashflow when cooling is considered as well. In this case, the return of investment is achieved after 21 years.

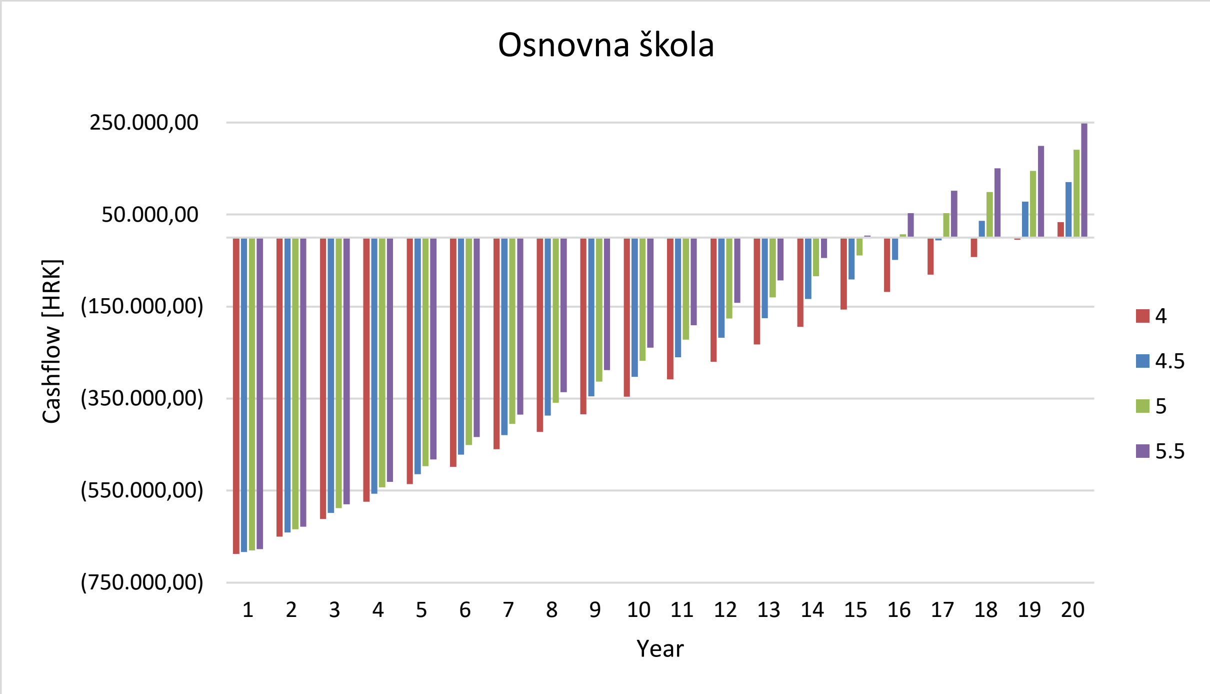


Figure 69 - Payback period for the elementary school in case of deployment of SWHP only for heating

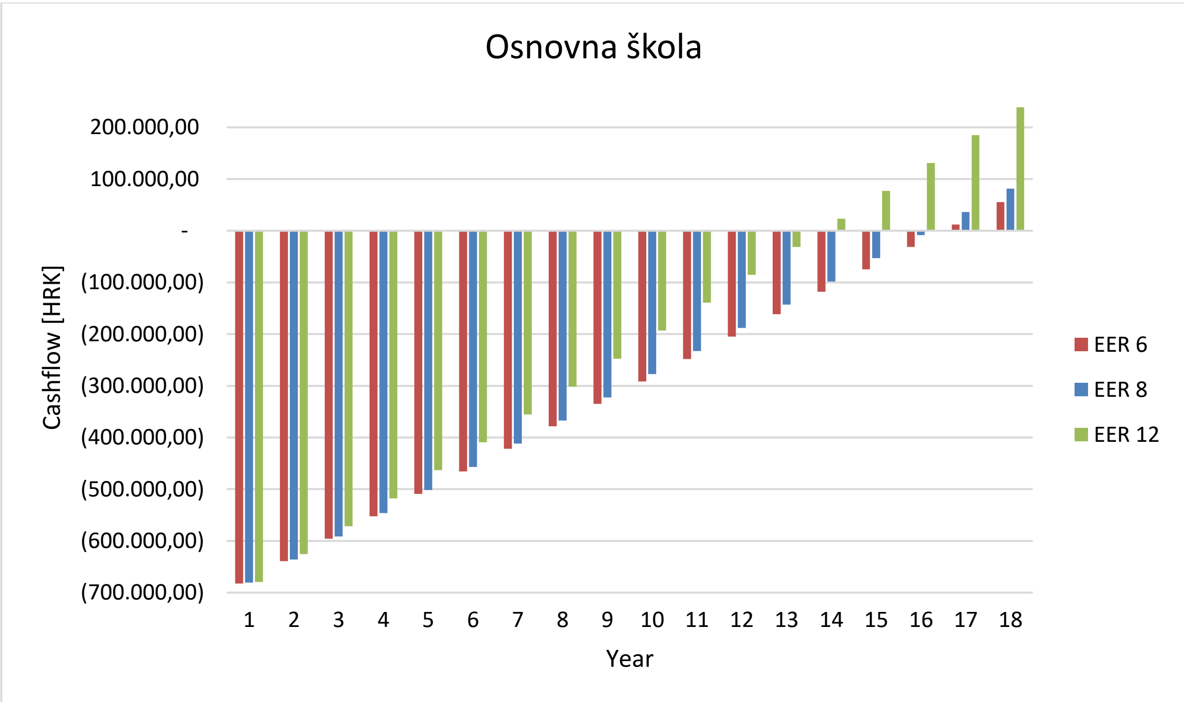


Figure 70 - Payback period for an elementary school in case of deployment of SWHP for heating and cooling

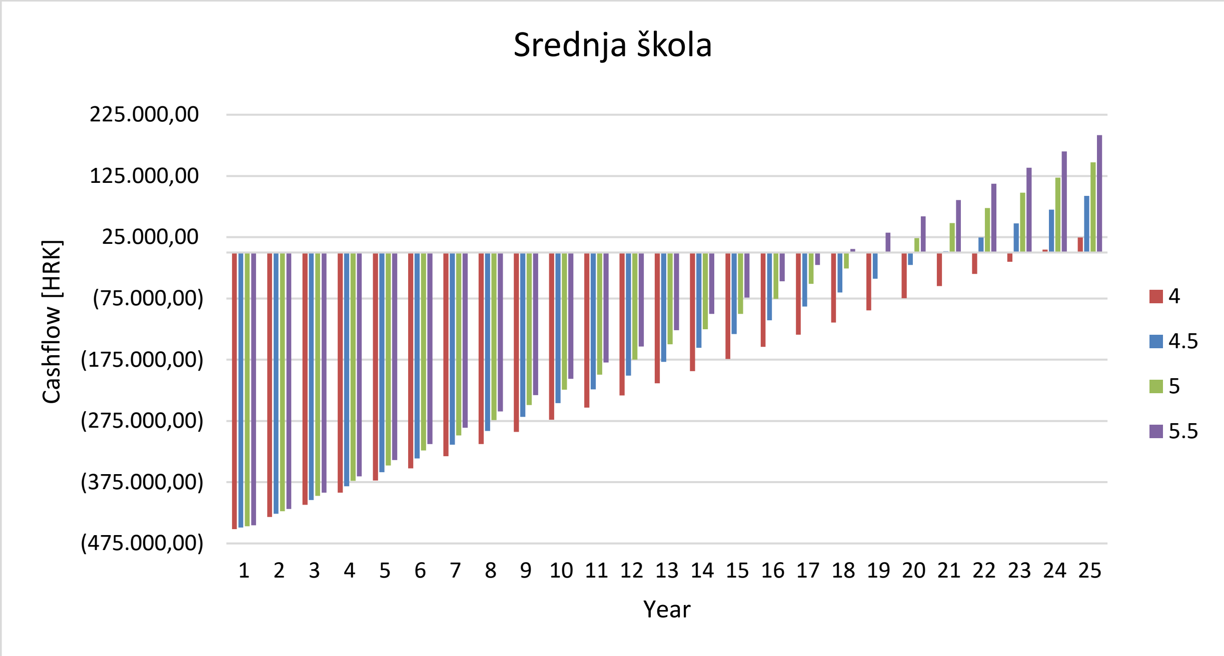


Figure 71 - Payback period for high school in case of deployment of SWHP only for heating

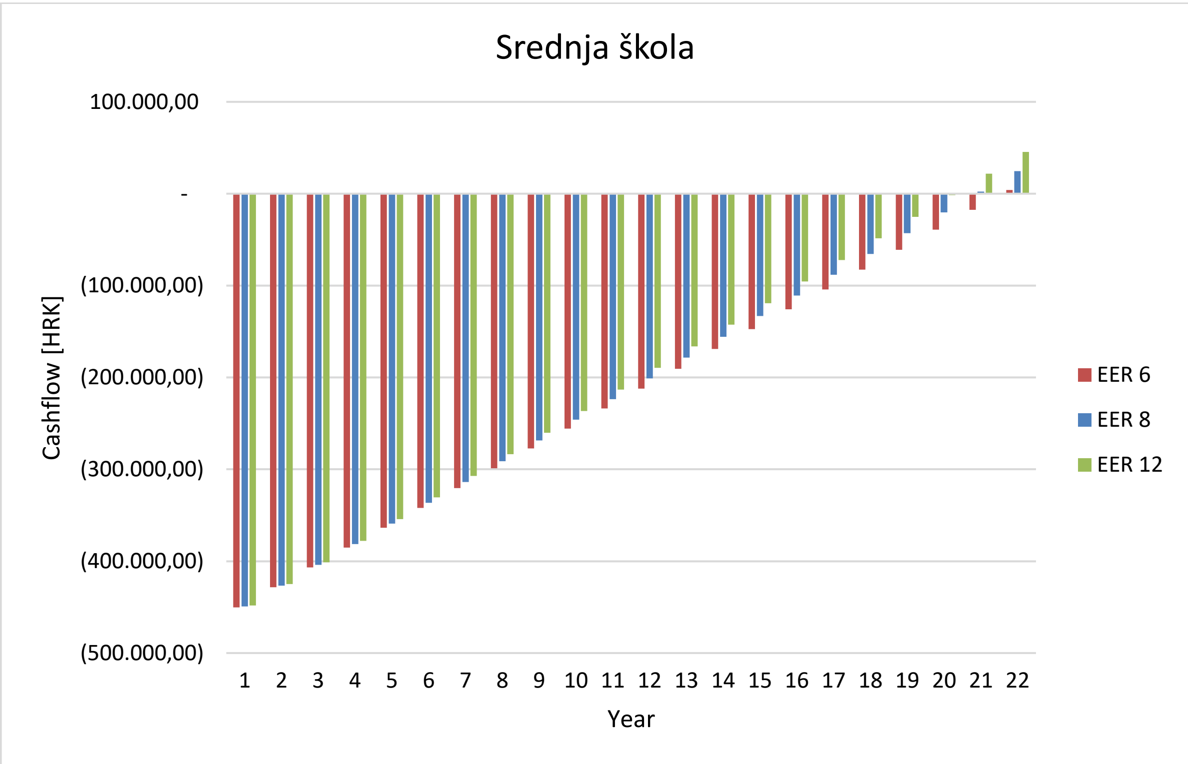


Figure 72 - Payback period for high school in case of deployment of SWHP for heating and cooling

To satisfy cooling demand, split systems are used with an annual electric consumption of 3 667 kWh. Installed capacities of the device are the following: six units with 5.3 kW (EER 3.2), and seven units with 5 kW (EER 5.2). Cooling demand was calculated by multiplying the electric consumption of each unit with their respective EER, and the obtained value is 14 696 kWh. Since the cooling demand is quite low, and installed devices have relatively high EER, the potential for savings is almost negligible, varying between 1 000 and 2 000 HRK.

3.2.7. Conclusion

Conducted analysis showed that there is remarkable potential for deployment of seawater heat pumps for considered pilot areas, and selected pilot locations. Return of investment can be achieved, depending on the type of building and COP, between 6 and 12 years in the best-case scenario. If the cooling demand is considered as well, the actual return of investment would be faster due to the increased load factor. Seawater heat pumps are an especially attractive solution for analysed objects since they are currently using some form of fossil fuel, which is not welcome in the future. Therefore, the deployment of seawater heat pumps can be beneficial not only in terms of reducing consumption of fossil fuels, but also in the reduction of CO_2 emissions, and decreasing the dependence on importing these fuels. Additionally, if the heat pumps are coupled with some other form of renewables, this would be even more beneficial since they can be used as thermal storage, especially important for the island and isolated communities. Having all this in mind, it is strongly recommended to continue with the potential analysis, which would consist of the actual calculation of heat and cooling load and respective annual energy demand, using real construction values. This way, the achieved savings, and derived benefits would be even higher, improving the overall cashflows and return of investment.

Evaluation of the potential for deployment of SWHP for additional buildings, analysed after the first meeting of the local HUB, was done by calculating the required system capacities and estimating the payback period. Since the purpose of buildings implies that they are not used during the summer period since there is a summer break, the need for cooling is pronouncedly lower. Therefore, the inclusion of cooling demand has a small influence on payback periods. Since the existing split systems can satisfy the required cooling demand, the need for a centralised cooling system is highly questionable. Since both considered buildings have mutual boiler rooms, a potential SWHP system should be considered simultaneously for both. This would allow higher system load and consequently shorter payback periods. The main concern and threat lie in the fact that the location of the buildings is not close to the sea, which would require drilling works for wells or the development of a complicated sweater intake and distribution system. Townhall of Mali Lošinj has great potential due to its location and vicinity of the sea. Also, they would benefit from SWHP for both, cooling, and heating purposes, which reduces the payback period significantly – to 10,9 years. Since they are public institutions it would be easier to implement a project like this.

3.3. DURA

3.3.1 Analysis of the pilot project location proposal

Based on the analysed potentials, in cooperation with the Client, propose one of the locations included in the subject area of Dubrovnik for the pilot area of the COASTENERGY project.

The proposal is to select one district in the city or one series of public urban buildings for which a central heating system would be built using blue energy. Seawater would be introduced into a central engine room where the main distribution pipeline for running process water through the city would be heated or cooled. An underground pipeline would be brought to each building in question while a local engine room with a built-in water-to-water heat pump would be built in each building. The building would be heated or cooled through the local engine room while the waste thermal energy of the building would be transported to the return pipeline.

In the south-eastern zone, fresh seawater would be taken into the system, and at this location, there would be a pumping station for receiving cold seawater as well as a central heating station in which pumping stations and a filter plant for seawater treatment would be installed. In addition, a system for reheating and cooling the technological water of the central heating and cooling system of the entire city would be installed. It is proposed to locate the central heating station of the city at this location given the direction of sea currents that bring fresh cold water.

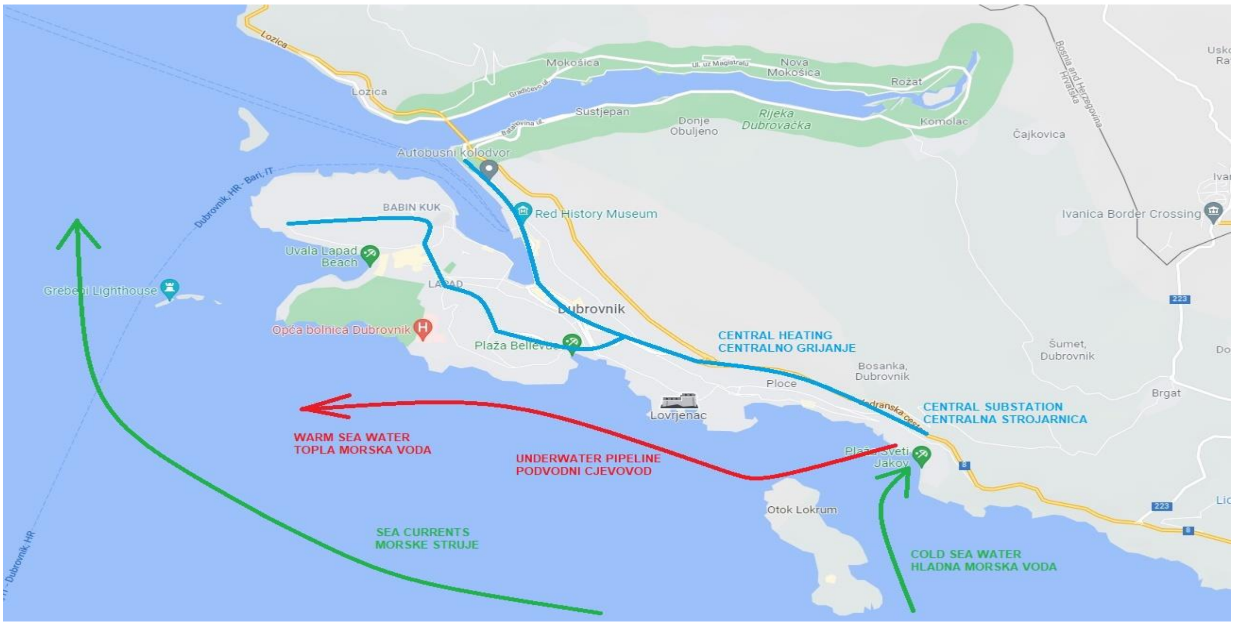


Figure 73 - Heating pipelines in Dubrovnik

All treated seawater would be drained through an underwater pipeline further from the engine room to the zone of active sea currents, which would take such heat-treated water further from the suction zone into the central system. During the summer, this wastewater would be reheated when the entire city is cooled, and the system would be dimensioned to prevent uncontrolled overflow of seawater with control of the outlet temperature of the seawater discharged heated into the sea. If the overheating is too high, adiabatic coolers can be provided in the central engine room to reduce the process water temperature of the entire system.

Technical and economic analysis of the pilot project

Based on the performed analysis, a pilot area of the COASTENERGY project must make a techno-economic analysis of a hypothetical heat use project.

As previously stated, the total area of all buildings in the city of Dubrovnik of 3.4 km^2 is assumed. Since buildings of different energy properties have been built, it is taken as a starting assumption that 100 kWh/m^{2}a of thermal energy is needed for heating.

3,4 km^2 x 1000 m x 1000 m x 100 kWh/m^{2}a = 340.000.000 kWh/a

= 340.000 MWh/a

= 340 GWh/a

As an initial assumption, it is accepted that it is necessary to provide 340 GWh/a of thermal energy for heating buildings.

Table 28 - Comparison of energy consumption for natural gas and system using SWHP

	Natural gas		**Heat pump water-water**	
Annual energy	kWh/god	340.000.000,00	kWh/god	340.000.000,00
System utilization	%	0,95	%	4,50
Heating value	kWh/m3	9,30	kWh/kWh	1,00
Annual consumption	m3	38.483.305,04	kWh	75.555.555,56
Energy price	kn/m3	4,20	kn/kWh	1,05
Unit price	kn/kWh	0,48	kn/kWh	0,23
Annual energy input	kWh/god	357.894.736,84	kWh/god	75.555.555,56
Annual energy cost	**kn**	**161.629.881,15**	**kn**	**79.333.333,33**
CO2 fuel emissions	kg/m3	2,0478	kg/kWh	0,0806
CO2 annual emissions	**kg**	**78.806.112,05**	**kg**	**6.086.251,85**
SO2 fuel emissions	kg/m3		kg/kWh	0,00024
SO2 annual emissions	**kg**		**kg**	**17.965,43**
NOx fuel emissions	kg/m3		kg/kWh	0,00014

NOx annual emissions	**kg**		**kg**	**10.745,68**
Heating savings			%	50,92

Compared to natural gas heating, using a water-to-water heat pump can open 50.9% of money savings while CO_2 emissions are 92% lower.

3.3.2 Preliminary solution of the pilot project

Based on the performed analysis, make a conceptual solution for one project of using a heat pump with the corresponding cost estimate; The conceptual design will serve as the basis for the preparation of a feasibility study; The conceptual design must offer a minimum of two variants of the heating/cooling system that will be analysed in parallel in the mentioned feasibility study;

The proposal is to select one district in the city or one series of public urban buildings for which a central heating system would be built using blue energy. Seawater would be introduced into a central engine room where the main distribution pipeline for running process water through the city would be heated or cooled. An underground pipeline would be brought to each building in question while a local engine room with a built-in water-to-water heat pump would be built in each building. The building would be heated or cooled through the local engine room while the waste thermal energy of the building would be transported to the return pipeline.

Activities for the construction of the first installation include:

- defining the subject project and the conceptual design
- defining the scope of installation and the number of buildings
- change of planning documentation for construction of hot water network
- production of technical documentation
- defining the economic construction of the investment
- conducting public procurement
- installation and commissioning
- monitoring the installation and preparation of periodic reports

It is proposed to build a local heating pipeline to which one city district would be connected to define on a small scale the possibility of building an installation for the entire city. The heating station can be designed with the possibility of a modular increase of thermal power as needed in accordance with the possible expansion of the installation to more buildings that would be heated and cooled throughout the year. Seawater is taken in the zone of the arrival of new water in accordance with the direction of the flow of sea currents. The used seawater is discharged further from the shore in the zone of outgoing sea currents through an underwater pipeline.

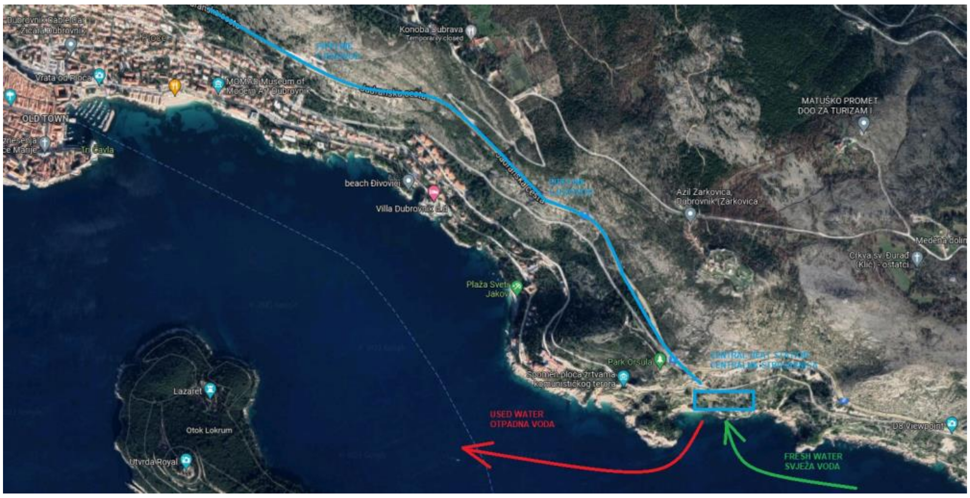


Figure 74 - Area for the heating station

3.4. UniCam

3.4.1.Technology applications

The choice of technologies was made through an analysis of the collected data, and correlating them to the morphological, structural and use characteristics of the sites.

3.4.2.Results analysis and interpretation

Port of Ancona project

In the port of Ancona, the works for the modernization of the port defence have recently been completed, with the lengthening of the breakwater to the NW and the subsequent lengthening of the NW pier. For this reason, the choice of the technology to be installed on this site has fallen upon a device that could be installed without modifying the stability of the present works and without requiring the construction of new volumes for its operation.

The device in question is the wave clapper of the Eco wave power and falls into the category of the Oscillation Body. 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 a shore located power station, which converts the energy from this motion into fluid pressure, which spins a generator, producing electricity.

Figure 75 - Wave clapper

The following figure (Figure 76) shows the power matrix for a system consisting of 100 flaps. At full capacity, each flap can produce up to 10 kW/h.

Significant height (m) \ Peak period (s)	4	5	6	7	8	9	10	11	12	13	14	15
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
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
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
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
2	1,000.00	1,000.00	847.94	726.8	635.95	565.29	508.76	462.51	423.97	391.36	363.4	339.17
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
1	317.98	254.38	211.98	181.7	158.99	141.32	127.19	115.63	105.99	97.84	90.85	84.79
0.5	79.49	63.6	53	45.43	39.75	35.33	31.8	28.91	26.5	24.46	22.71	21.2

Figure 76 - Power Matrix for a Wave clapper power station with an installed capacity of 1 MW with 100 floaters. (Eco Wave Power).

Using the Wave to Wire models [23], the power matrices of each device were computed. By multiplying the power matrix of the device with the wave scatter diagrams at the Port of Ancona site, the annual mean absorbed power was derived [24].

Figure 77 - Port of Ancona site.

By planning the installation of 200 flats along the NE dock of the port of Ancona (highlighted in red in Figure 77), the plant can produce 4 GW/y of energy, with an hourly average of 457 kW/h, therefore approximately 2.3 kW/h for each flap installed.

San Benedetto del Tronto project

For San Benedetto del Tronto, the analysis regarded two possible pilot installations in two different sites. It was thought to install coastal defence works that limit erosion by exploiting the wave motion in front of the Sentina Nature Reserve, trying to combine energy production with anti-erosion systems.

Moreover, it was decided to use the breakwater of the port of San Benedetto for the installation of wave energy conversion systems as already planned for the Port of Ancona. As the first sector of the pier of the port of San Benedetto falls into the seafront and therefore has a strong presence of tourism, to limit the visual impact of the system, it was decided to install a 100-float system on the outer sector of the pier (indicated as a red line in Figure 79).

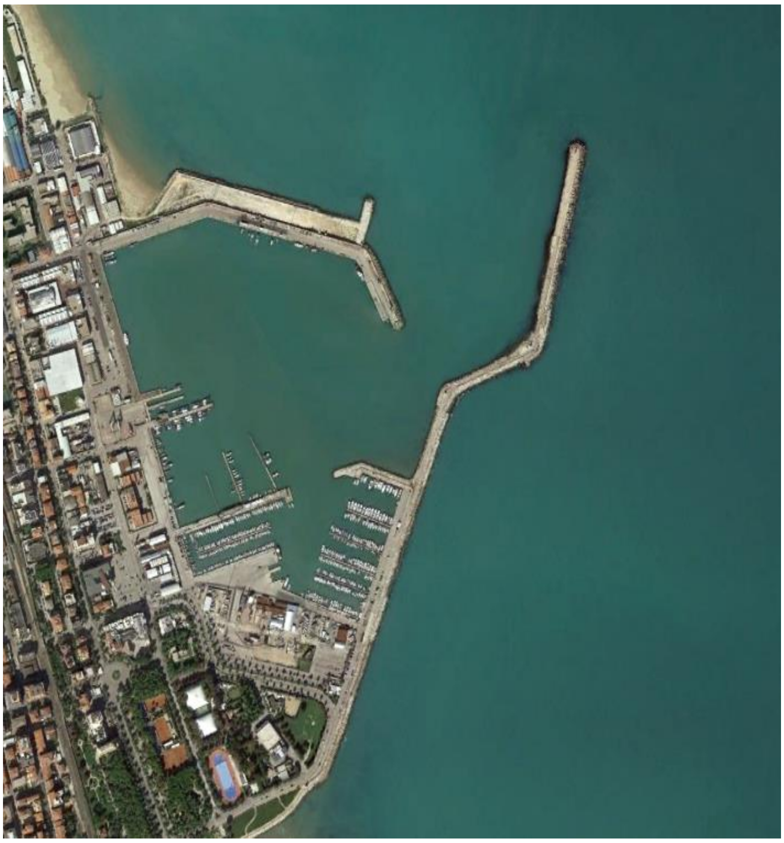


Figure 78 - Port of San Benedetto del Tronto site.

As in the case of the Port of Ancona, by multiplying the data of the power matrix of the device with the sea states regressing for the site, the average energy produced was calculated. By planning a 100-float system along the breakwater, the plant can produce 1.8 GW/y, with an hourly average of 208 kW/h, therefore approximately 2.08 kW/h for each flap installed [24].

For the Sentina Reserve, comparing the devices on the market with the characteristics of the Marche coast, it was decided to place Oscillating Wave Surge Converters (OWSC) systems parallel to the coast in the nearshore area. The OWSC systems consist of a simple pitching flap oscillating about a fixed axis close to the sea bottom, suitable for shallow and intermediate water depth. Furthermore, the OWSC system has the advantage of helping to limit the erosive action of the wave motion on the coasts.

The device chosen for this site is the wave roller: working in the near-shore zone at a depth of 8 meters, it absorbs the energy contained primarily in the horizontal motion of water, thus reducing the wave power at the shoreline.

A single device at full capacity can produce up to 3 kW/h as shown by the power matrix in Figure 81.[24]

Figure 79 - Sentina Natural Reserve site.

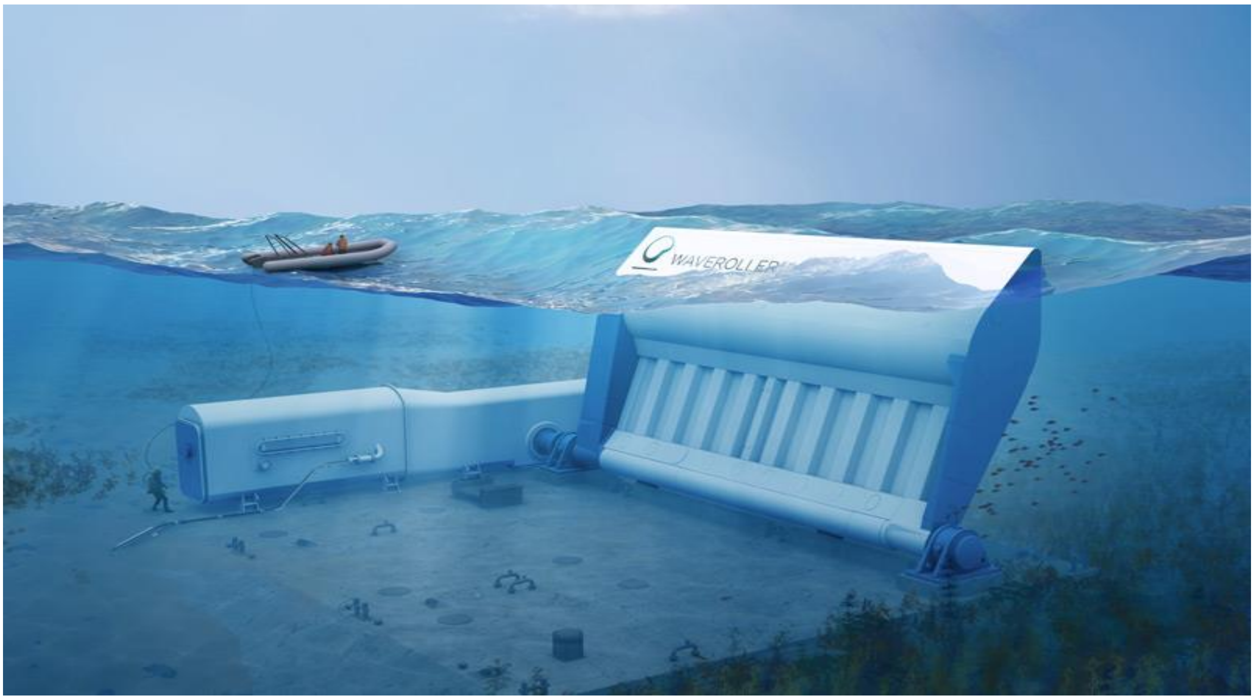


Figure 80 - Wave roller (render)

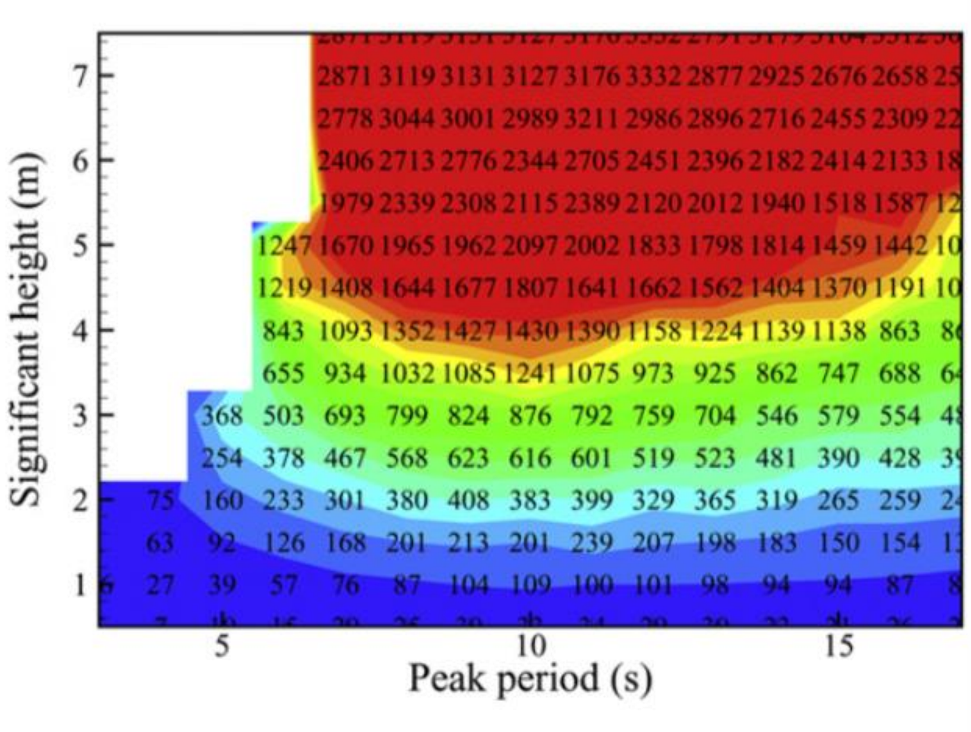


Figure 81 - Waveroller Power Matrix.

In the case of the Sentina Natural reserve, the installation of a series of 30 devices distanced about 20 meters one from the other was planned. In this way, it will be possible to guarantee not only the production of energy but also the protection of the coast from erosion.

As for the previous sites, the potentials were calculated by multiplying the power matrix by the sea states. The result of these calculations is that 30 devices installed nearshore can produce 20 GW/y of energy, with an hourly average of 78.3 kW/h for each device installed.

3.4.3.Law and regulations

Common issues

Since Italian laws and regulations – at both national and regional level – seldom explicitly mention or consider Blue Energy systems, 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 analysis of current regulations shows that all newly installed wave energy conversion systems need to:

- Undergo a screening procedure for the Environmental Impact Assessment, according to the Regional Law no. 11/2019 and in compliance with the national Legislative Decree nr. 152/2006. Applications must be submitted to the regional office for environmental assessments and authorizations – Service “Protection, layout and management of the territory”
- Obtain a regional permit for electrical activities, according to Regional Law n. 10/1999. Applications shall be submitted to the Regional Office for public works and soil protection (contact point for the design of electrical installations up to 150.000 V)
- Submit to the Connection Unit of Terna (management body of the Italian transmission network) a connection request for connecting the installations to the national grid.
- Obtain authorization for underwater works, if needed, from the Coast Guard (Law 24/03/2012, nr. 27, art. 16, comma 2).
- Obtain a temporary “maritime public concession” for the use of publicly owned facilities/areas, released by the Ministry for Infrastructure and Transports (according to Law no. 244/2007, Legislative Decree no. 387/2003, and Navigation rules - art. 36) either directly (for concessions longer than 15 years) or through the competent maritime authority – i.e., the Coast Guard.

Wave energy converters in the Ports of Ancona and San Benedetto del Tronto

The Ports of Ancona and San Benedetto del Tronto are both managed by an inter-regional Port authority for the Central Adriatic Sea (called in Italian “Autorità di Sistema Portuale del Mare Adriatico Centrale”), which manages also the ports of Pesaro, Pescara and Ortona. This Authority oversees implementing the Regional Ports Plan (prepared by the Region and approved in 2010), by preparing a common Master Plan for all the ports it manages in the adjoining regions of Marche and Abruzzo. This Master Plan is currently under preparation. In April 2020, the Authority published a European call for tenders covering: the strategic planning for the whole ports system (“Documento di pianificazione strategica di sistema”); the update of each port’s detailed plan; and the energy plan for the port system (“Documento di pianificazione energetica ambientale del sistema portuale”), as required by the national law 84/1994.

This ongoing planning process and the involvement of the Port Authority in the Local Coastal Energy Hub could represent a good opportunity for COASTENERGY to mainstream Blue Energy topics into the port’s planning instruments, and to transfer this approach to the other ports managed by the Authority.

From the administrative point of view, the Region can issue opinions on the compliance of port structures projects with the Regional Ports Plan and oversees administrative procedures related to the design and implementation of the interventions of construction and rehabilitation of regional ports. Also, the involved municipalities (according to regional law nr. 10/1999) have jurisdiction over this kind of intervention.

The installation of a wave energy conversion system in the ports of Ancona and San Benedetto del Tronto – besides obtaining the authorizations mentioned above - must therefore receive the favourable opinion of:

- Marche Region – Service for Infrastructures, Transports and Energy
- Port Authority for the Central Adriatic Sea
- Municipality involved

The installation of the selected devices is not in contrast neither with the Regional Ports Plan, nor with the Triennial Operational Programme of the Port Authority, nor with the Master plan of the port of San Benedetto del Tronto. Nevertheless, since onshore electrical works in the Port of Ancona will likely affect the shipyards area managed by the public company Fincantieri, an engagement of the company's representatives would be appropriate. It is also worth stressing that, while the Port of Ancona is totally under the jurisdiction of the Italian State, in San Benedetto del Tronto the commercial port is managed by the State, and the marina by the Region: the co-existence of these two jurisdictions can make the authorization procedure more complicated.

Wave energy converters for coastal protection in the Sentina reserve

The Marche Region oversees the permitting of structural interventions related to coastal protection, which must also undergo the EIA screening (see 3.1) and be approved by the Civil Engineering Department (that has jurisdiction on works interfering with the hydraulic balance of littorals).

The main regulatory instrument to take as a reference is the regional-level Integrated Coastal Zone Management Plan (ICZM Plan). This Plan, inspired by integrated coastal management principles, defines and regulates the structural interventions that are needed for coastal protection. According to the Plan, structural interventions regarding coastal protection must always comply with the following prescriptions:

- Reconstitution of sea-grass beds and dune environments, whenever the intervention entails their alteration;
- Implementation of monitoring and mitigation measures;
- Assessment of the compatibility of interventions with the conservation measures regarding the involved Natura2000 sites.

The Plan also 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 [25].

Moreover, the Plan recalls that the national guidelines for coastal protection contemplate the installation of wave energy systems as a viable option to reduce coastal erosion – a major problem in the coastal section considered.

As regards jurisdictions, the Regional Law n. 15/2004 "Regulation of competences in the field of coastal protection" states that:

- the Region oversees approving projects regarding coastal protection works/structures, and issuing permits for the installation of cables and ducts;
- the Municipalities design and implement coastal protection interventions (when commissioned by the competent regional service) and oversee the maintenance of coastal protection structures (with regional co-financing).

Therefore, the installation of the pilot plant and the related cables – besides obtaining the authorizations already mentioned in the 'Common issues' section – is subject to submitting two distinct permitting applications, both on the Regional body. However, the combined competences of regional and local level bodies can make implementation procedures more complicated.

3.4.4. Economic assessment

The economic evaluation for both pilot areas was partially performed. As regards the costs of the installations, the only data available concerns the wave clapper, for an Eco Wave Power wave energy power station with an installed capacity of 1MW with 100 floaters the cost of the system is approximately 1.2 million USD/1.02 million € (not including installation and connection to the grid which varies per the specific location of installation). Unfortunately, it was not possible to make a preliminary economic analysis for the wave roller because we have not received any answers from the device manufacturers (AW-energy).

3.4.5. Conclusion

The locations identified were chosen after consulting stakeholders during the local HUBs. Other locations could be taken into consideration since in other areas of our region coastal defence works are planned as indicated by some stakeholders.

The preliminary economic analysis, in addition to being incomplete due to the lack of answers from the manufacturers of the wave roller, requires further investigation, especially as regards the installation of the devices. As this technology is relatively young in the Mediterranean Sea and even more so in the Adriatic, it is difficult to find information on the possible costs of implementation because the companies that work in the sector of installations in the sea do not fully know the technology. Furthermore, there is a lack of historical data on possible maintenance costs, this is because most of the devices are prototypes that, once installed, were subsequently removed after short periods.

From a technical point of view, the production of energy from wave energy converters in our region is strongly affected by seasonality, in fact, except for limited summer storms, the period of energy production is limited to the autumn and winter seasons, from October to March, while in the spring-summer period the energy produced is relatively low.

3.5. UniUd

3.5.1. Selected technology potential assessment

More specifically, the idea would consist in creating an open loop in which seawater would be circulated, to serve along the route one or more heat exchangers that allow heat exchange between seawater and glycol fluid.

For existing buildings, it could be possible to intervene in the optimization of the heating plant, when replacing the existing boiler due to wear. The use of hydrothermal energy in combination with a medium or high-temperature heat pump would represent a valid solution capable of guaranteeing, at the same time, significant savings in primary energy with the simultaneous use of a renewable energy source.

The plant would use an open loop with seawater that would be drawn at a depth of a few meters in the small bay in front and would be pumped to the power plant where the heat exchangers are located. In this way, the seawater would transfer its thermal energy to a secondary closed circuit, where technical water would flow. Heat pumps could guarantee a large part of the energy needs for heating, cooling and the production of sanitary water.

This solution would be achieved through a conceptually simple infrastructure (mini-primary district heating network), equipped with polyethylene pipes positioned at an adequate depth to allow each building to connect to the supply and return of seawater in an open circuit, or to connect to an intermediate technical water network in a closed circuit, which network would require a common exchanger with the sea resource.

Single- or double-stage heat pumps would transfer the heat supplied by the hydrothermal source to the distribution systems and the heating and cooling terminals. The use of two-stage compression heat pumps would also make it possible to produce the domestic hot water necessary to meet the needs of users.

The electric heat pump (single or double stage) would be able to transfer the thermal energy contained in the seawater to the internal systems of the buildings served. For new buildings or in any case in the case of low-temperature internal systems, traditional heat pumps could replace the condensing boiler, as a heat generator for the user to be served.

3.5.2.Economic assessment

Objective advantages can be attributed to the geothermal and hydrothermal energy exploitation plant, mainly from an energy and environmental point of view, but also from a management and economic point of view. This solution would allow:

1. Concentrate the production of heating and cooling in a single system, with management advantages and optimization of yields and consumption;
2. Preserve the management autonomy of the buildings served and the individual production of heating, domestic hot water and room conditioning;
3. Reduce CO2 emissions for urban heating;
4. Reduce maintenance costs.

As far as implementation costs are concerned, it is estimated that a district heating distribution network costs around 1 million per km. However, for a more detailed evaluation on the economic and managerial front, it will be necessary to develop precise feasibility plans, to define in detail the economic and financial plans, fundamental for the evaluation of interventions of this type.

3.5.3.Conclusion

The proposal of the pilot location was discussed with local stakeholders and it will need further assessment. Particularly, we will deeply investigate the potential assessment and financial aspects.

The next steps of analysis will be clearly defining the project and doing a more precise energy assessment. We identified many advantages as to concentrate the production of heating and cooling in a single system, with management advantages and optimization of consumption. As regards environmental sustainability, we aim to reduce CO_2 emissions for urban heating. However, we need to consider all the aspects related to sea warming with consequent alteration of the marine flora and fauna.

Our proposal aims to also offer an innovative opportunity to reduce maintenance costs. The next step will be a detailed exploration of the system feasibility both in terms of beneficiaries and of economic value.

3.6. Chieti-Pescara

3.6.1. Selected technologies potential assessment

Selected technologies potential assessment of Pescara Marina

The following figure shows pilot locations within the structural plan of Pescara Marina. As shown in the legend, we hypothesized the use of three onshore wave energy converters (represented through ideograms, not real representations), namely OWC, OBS and clappers. The latter has been considered in limited areas that should not limit shipping routes and accessibility to the port. Choices of pilot locations are also due to the analysis of wave energy potentials (see direction and intensity of waves).

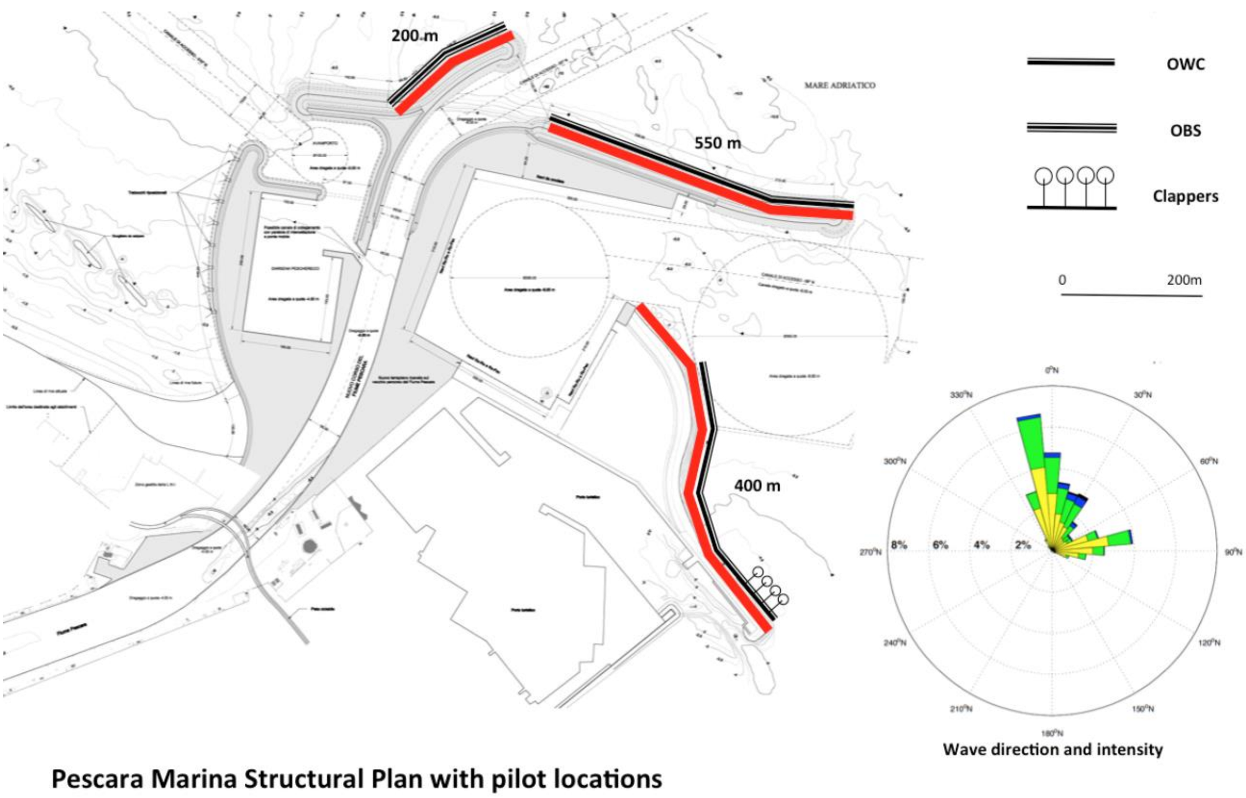


Figure 82 - Map of the pilot area Pescara Marina and possible pilot locations.

Based on consultations with stakeholders and technical requirements, we partially confirm the hypothesis made in D.3.4.1. A preliminary estimate of potential production yields for a business plan follows (prudential estimate):

- *Oscillating water columns* - estimated electricity production in 900 m pier: over 3000 MWh/yr (average 350 MWh/yr per 100m)
- *Overtopping Breakwater* - estimated electricity production in 200 m pier: 400 MWh/yr (average 200 MWh/yr per 100m)
- *Wave clappers* - estimated electricity production in 50 m pier: over 150 MWh/yr (average 350 MWh/yr per 100m);
- Seawater-based heat pumps: installation for 400,000 m^3 of built volumes (e.g. new Maritime Station of 2000 m3 and other existing buildings), heat energy demand: 100 MWh/yr; CoP>4; electricity demand: 25 MWh/yr.

Selected technologies potential assessment for Vasto Marina

The following figure shows pilot locations within the structural plan of Vasto Marina. As shown in the legend, we hypothesized the use of two out of three onshore wave energy converters (represented by ideograms, not real representations), namely OWC and clappers. The latter has been considered in limited areas that should not limit shipping routes and accessibility to the port. Choices of pilot locations are also due to the analysis of wave energy potentials (see direction and intensity of waves taken from the buoy in Pescara).

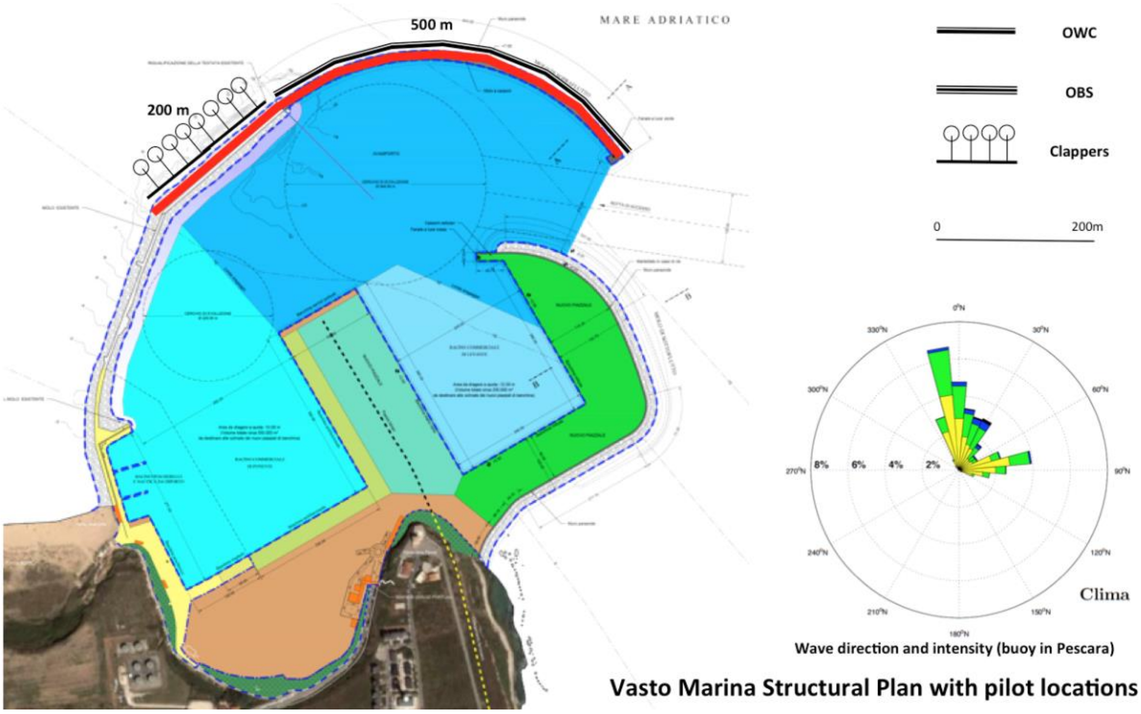


Figure 83 - Map of the pilot area Vasto Marina and possible pilot locations.

Based on consultations with stakeholders and technical requirements, we partially confirm the hypothesis made in D.3.4.1. A preliminary estimate of potential production yields for a business plan follows (prudential estimate):

- *Oscillating water columns* - estimated electricity production in 500 m pier: around 1750 MWh/yr (average 350 MWh/yr per 100m)
- *Overtopping Breakwater* – not planned due to lower production yield (average 200 MWh/yr per 100m)
- *Wave clappers* - estimated electricity production in 200 m pier: over 700 MWh/yr (average 350 MWh/yr per 100m);
- Seawater-based heat pumps: not planned.

3.6.2.Results analysis and interpretation

Results analysis for Pescara Marina

Based on the hypothetical installation shown above, wave energy converters embedded in piers can generate over 3500 MWh of electricity per year. The current electricity demand of the Marina (including all services) is around 900 MWh/yr. The additional electricity demand for heating/cooling 400,000 m^3 buildings is around 100 MWh/yr. The potential production of wave energy converters in new piers would potentially support the demand of the Pescara Marina (including heat pump systems) and still export electricity to the grid (2500 MWh/yr).
All the estimates are in a preliminary form and still need to be confirmed based on additional information on dimensions of piers and buildings (m^3 to be supplied by heat pumps).

Results analysis for Vasto Marina

Based on the hypothetical installation shown above, wave energy converters embedded in piers can generate over 2400 MWh of electricity per year.
All the estimate is in preliminary form and still need to be confirmed based on additional information on dimensions of piers and buildings (m^3 to be supplied by heat pumps).

3.6.3.Economic assessment

The economic assessment for both the pilot areas has not been performed yet. Costs of installations at this stage are not clear enough due to the technology readiness level of the devices. Nevertheless, a few observations follow:

- the technology readiness level of devices does not allow to determine the costs of installations. The production of prototypes can be expected to be expensive (out of market profitability) due to uncertainty of operations for manufacturing and maintenance in time, nevertheless, it is expected to be optimised in the future to become cost-effective.

- At this stage, economic incentives are necessary to reduce the risks of private investments and typically prompt innovation for the exploitation of renewable energy sources.
- Pilot projects consider the future scenario as foreseen in the Structural Plan of ports, rather than their current configuration. The perspective of new interventions and extensions is a good opportunity to promote the integration of blue energy in 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.

3.6.4.Conclusion

The pilot locations proposed are currently under discussion with local stakeholders and need additional analyses to increase the feasibility of proposals and guarantee their sustainability.

Pilot projects and assessments described above, as well as sustainability, should be deeper investigated and determined. Especially, economic assessments have a high level of uncertainty and, at this stage, installations would require access to public funds and incentives to become cost-effective.

After additional studies and consultation with stakeholders, the pilot project will offer opportunities for innovative initiatives to be implemented through structural funds or by applying to other suitable calls for proposals aimed at supporting innovation and sustainable energy. The consultation process and investigation of scenarios are still in progress and foreseen during the next project activities.

3.7. Community of Mediterranean Universities

3.7.1 Pre-feasibility study

Wave motion is considered the largest unused renewable energy source on the planet: it has been calculated that, if exploited, it would yield 80 trillion kWh, i.e., five times the annual electricity needs of the whole world.

Wave energy is the most constant among the renewable energies. It is a result of the concentration of the energy produced by the wind, which in turn concentrates the energy produced by the heating of the atmosphere due to the sun. The average power of waves is about 2-3 kW/sqm, four to five times the power obtainable from the wind, and up to twenty times the power obtainable from photovoltaics.

3.7.2 Potential assessment of selected technologies

The characteristics of the three proposed technologies and the framework of the pilot area have been described in the previous paragraphs. This paragraph outlines a possible application scenario.

The Big Port of Mola di Bari is composed of two piers, one to the west one to the east (Molo di Levante).

The western pier has a total length of about 600 meters and consists of three stretches, respectively 250 m, 150 m, and 200 m long. The eastern pier is about 700 m long and consists of two stretches of 350 m each.

The dominant sea currents are parallel to the coastline, moving from the northwest to the southeast.

The depth ranges of the area are:

- not exceeding 20 m within 1 km from the coast;
- from 20 m to 50 m between 1 km and 3 km from the coast;
- from 50 m to 80 m between 3 km and 5 km from the coast;
- from 80 to 100 m between 5 km and 7 km from the coast.

At 1 km from the coast, wave power is about 1 kW/m, and wave height is about 0.5 m. These figures, taken from the webGIS of the Interreg Maestrale project, refer to inter-annual averages.

The table below shows, for each selected technology, the production potential, dimensions, and depth bands where installation is possible.

Table 29 - Comparison of the technologies

Technology	Length	Width	Height a.s.l.	Depth band	Distance between devices	Nominal power	Estimated electricity production	Families served
Iswec Off-shore	5/8 m	5/8 m	2/3 m	25/50 m	> 30 m	51 kW	446.76 MWh/ year	165
Penguin Off-shore	16 m	30 m	7 m	25/50 m	> 30 m	500 kW	4,380 MWh/ year	1,622
Obrec On-shore	3/5 m	8/12 m	-	-	0 m	3 kW	26.28 MWh/year	10

- The nominal power of ISWEC (51 kW) refers to the most recent data about the peak power reached by the device installed off Ravenna and serving the ENI oil platform.
- Estimated electricity production is intended as the nominal power, multiplied by 24 hours, multiplied by 365 days.
- The electricity consumption for a family unit consisting of 2/3 people, as indicated by the Italian Authority for Energy and Gas, is estimated at approximately 2.7 MWh/year.

3.7.3 Overall description of the application

The proposed Blue Energy application in the Big Port of Mola di Bari meets the request by the Municipality to be able to make the new floating district, the piers, and the port area completely self-sustainable in terms of energy consumption.

Considering 2.7 MWh/year as the standard energy need of a family, the new district, which will entail the building of approximately 90 residential units, will have an estimated energy consumption of approximately 243 MWh/year. Three different installation alternatives are proposed to meet such needs:

- installation of one ISWEC device with a nominal power of 51 kW and 2 OBREC modules with a nominal power of 3 kW each, for a total of 57 kW;
- installation of a Penguin device with a 25% scale and a nominal power of about 125 kW (this value has been assumed as being proportional to the downscaling ratio);
- installation of 10 OBREC modules with a total nominal power of 30 kW.

The ISWEC and Penguin offshore devices would find an ideal location at a distance from the coastline between 1 and 3 km, with depths between 25 m and 50 m and wave heights greater than 0.5 m: these are the minimum requirements necessary for both technologies to be productive.

The OBREC modules would be built on the second stretch of the western pier (about 150 meters in length); since the length of a single OBREC module can reach a maximum of 5 m, a series of 10 modules would cover a maximum length of 50 m out of the 150 available. This part of the pier was chosen because it is perpendicular to the currents, it is, therefore, more suitable for hosting such an energy production system; on the other hand, the eastern stretch would be unsuitable because it is parallel to the dominant sea currents.

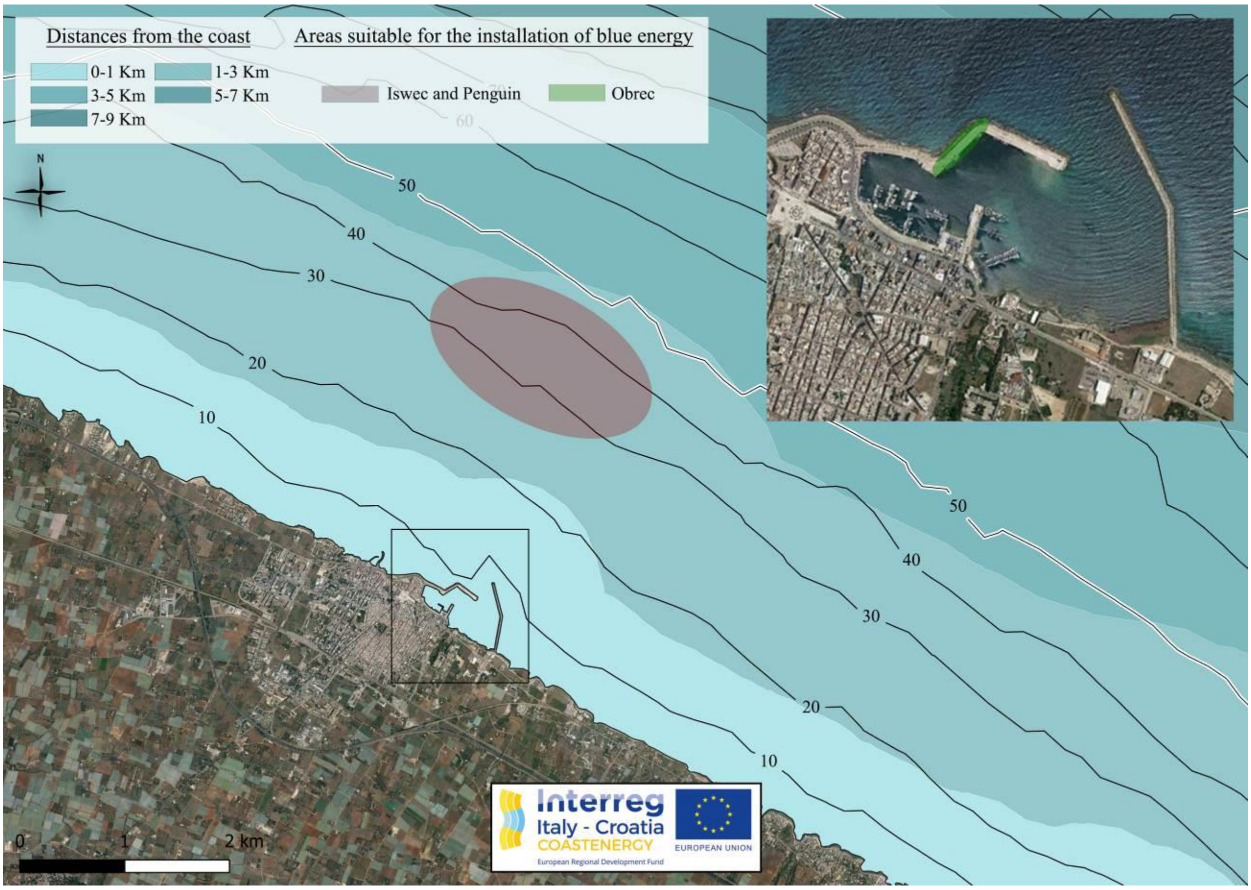


Figure 84 - Areas are suitable for the installation of blue energy systems.

3.7.4 Analysis and interpretation of results

The first proposal, which entails the installation of one ISWEC device and two OBREC modules, in addition to meeting the needs of the new floating district, with an estimated electricity production of about 499 MWh/year, would also be able to power the public lighting of the entire port area for a total length of about 2.2 km, i.e. 150 lighting units with nominal unit power of 100 W each, spaced 15 m apart, for a total of 44 MWh/year, calculated on an average of 8 hours per night for 365 days. Furthermore, a sufficient energy stock would still be available to meet the energy needs of 20 charging stations for boats, considering a nominal power of 1 kW for a single station, for a total of 175 MWh/year.

This solution would therefore achieve the goal of:

- meeting the energy demand of 90 housing units in the new floating district (243 MWh/year);
- providing energy for the public lighting of the entire port area with 150 lighting units (44 MWh/year);
- powering 20 charging stations for boats (175 MWh/year).

The second proposal (installation of a single Penguin device scaled to 25%, nominal power 125 kW, estimated production 1,095 MWh/year) would equally be able to produce 462 MWh/year (new floating district, public lighting in the port area, and charging stations for boats); in addition, thanks to an energy production surplus of about 630 MWh/year, it would be possible to power several charging stations for electric cars to be installed near the pier. However, it should be noted that this solution is the least applicable since there are no "scaled" devices yet for the Penguin technology.

The third proposal entails the installation of 10 OBREC modules with a nominal power of 3 kW each, for a total of 30 kW, resulting in an estimated electricity production of about 260 MWh/year, which is higher than what necessary to make the new floating district self-sufficient.

These results could be a driver for further feasibility studies of Blue Energy applications in the Italian seas, and a desirable growth of this energy source, which has been so far only poorly studied and applied.

Moreover, in the specific case of Mola di Bari, the installation of these Blue Energy systems would perfectly fit into a cycle of urban regeneration plans, which have been carried out since 2011.

3.7.5 Economic assessment

In an optimistic scenario, based on the current level of investments, about 3.9 GW of global cumulative installed capacity for the marine energy market are estimated for 2030. More than 90% of this capacity would be in Europe. The most advanced projects make use of the tidal stream technology, which is considered the most promising.

Like any other form of renewable energy, ocean energy has relatively higher capital expenditure costs (for example, the installation of devices into the water), and operating costs (for example, maintenance, fuel, etc.). "The Levelized cost of energy (LCoE) of fossil fuels", as described in the conclusions of a report drawn up by Cogea and WavEC[7], "could remain lower than that of ocean energies for a long time; but the higher CAPEX/OPEX ratio of ocean energy is promising because it reveals that resources are spent to create long-term value".

The authors of the report estimate that the target of 10-euro cents per kWh could be reached by 2030 for tidal streams and by 2035 for wave energy. The report also recalls that, so far, over 6 billion € have been invested worldwide in marine projects, 75% of which come from private funding.

The deployment of marine energy would also meet the recommendations of Directive 2014/89/EU, which established a common framework for the implementation of maritime spatial planning and integrated

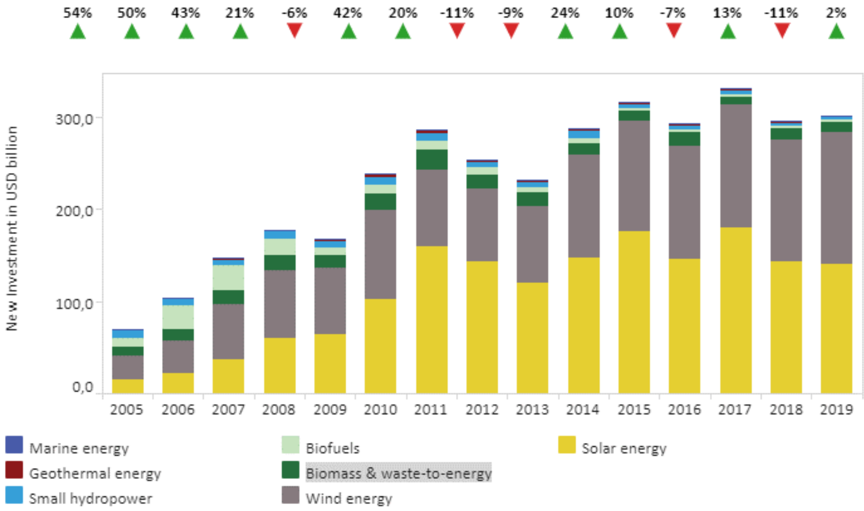
[7] This report (**Market study on ocean energy** – https://op.europa.eu/en/publication-detail/-/publication) was written by Cogea and WavEC and commissioned by the European Commission. It describes three development scenarios for the marine energy market. The analysis takes into consideration three technologies: wave exploitation, tidal exploitation (tidal range and tidal stream, depending on whether one focuses on the high-low or forward-backward movements of the water) and the exploitation of thalassothermic energy (OTEC, i.e. Ocean Thermal Energy Conversion). For each technology, the authors assessed the possible developments in annual and cumulative capacity, and the evolution of the LCoE, i.e. the cost of electricity.

coastal management by the Member States, to promote the growth and sustainable development of maritime economies, areas, and marine resources.

Research, innovation, and competitiveness are at the heart of the EU strategies, which entail a new European approach to research and innovation in the energy sector to accelerate the transformation of the energy system and ensure that promising, innovative zero-emission energy technologies reach the market, bridging the remaining gap between research projects or demonstration prototypes and their commercial use. The EU recommends focusing the efforts on a limited number of promising technologies, aiming at a reduction in LCoE for wave energy converters to 20-euro cent/kWh by 2025, 15-euro cent/kWh by 2030-, and 10-euro cent/kWh by 2035.

These data are also confirmed by the authors of the report: in fact, they estimate that the target of 10-euro cent/kWh could be reached by 2030 for tidal streams and by 2035 for wave energy.

In terms of new investments and installed power, the Blue Energy sector is still at its beginning as shown by the data in the image below, in 2019, of the $ 300.60 billion globally invested in clean energy, $ 141 billion was invested in solar energy, $ 142.70 billion in wind energy, and only $ 0.20 billion in Blue Energy.

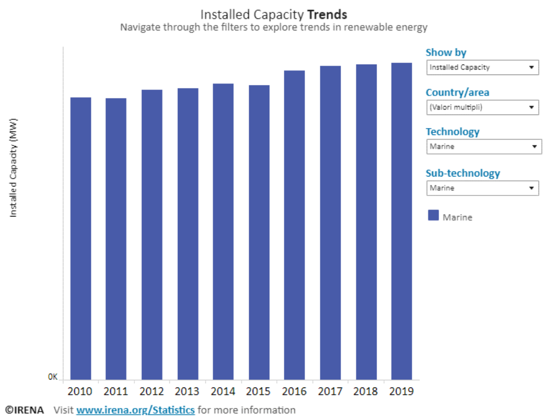


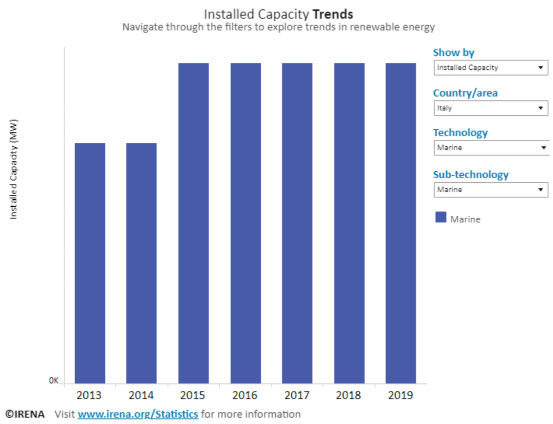
Global investments in clean energy in 2019: 300,60 USD billion

Solar energy:	141,00	USD billion
Wind energy:	142,70	USD billion
Biomass waste-to-energy:	11,20	USD billion
Biofuels energy:	3,00	USD billion
Small hydropower:	2,50	USD billion
Marine energy:	0,20	USD billion

Figure 85 - Global investments in clean energy in 2019

The 2019 data reveal the presence of Blue Energy plants for 247.45 MW in the European seas; of these, only a negligible share of 0.20 MW is in the Italian seas and coasts[8].





Installed capacity in Europe in 2019:

247.45 MW

Installed capacity in Italy in 2019:

0.20 MW

Figure 86 - Installed capacities for marine energy in Europe and Italy.

All recent reports pay particular attention to the barriers that are still hindering the industrial and commercial launch of marine energy technologies (technological development, finance, consensus, environmental issues, availability of network infrastructure). Eliminating the current barriers to project implementation is indeed a priority, along with providing access to significant, stable, and predictable funding.

Although these technologies could significantly contribute to the production of clean energy for all coastal areas and islands of the Adriatic Sea, their huge potential is nowadays almost unexploited.

Even if at present there is still no precise data allowing investors to carry out a precise economic assessment, the technologies selected for the Apulian pilot area, and ISWEC in particular, have achieved extraordinary results in terms of production, and substantially reached the grid parity.

[8] Source: IRENA (International Renewable Energy Agency), https://www.irena.org/ocean

3.8. Municipality of Ploče

The feasibility study is of exceptional importance for the adoption of key strategic determinants for the improvement of the existing energy infrastructure and civil reconstruction of the existing facility at the selected location. Therefore, it is necessary to assess the energy potential of the selected technological solution. At the same time, the chosen development determinants must be justified by key economic indicators such as the value of the total investment and the estimated duration of the payback period.

3.8.1. Selected technology potential assessment

The exact energy potential of the seawater/water heat pump can only be assessed after the construction of an exploratory well and a detailed analysis of geological data on seawater quality and temperature. However, the selected pilot site is located at a relatively short distance from the sea, thus fulfilling the necessary condition for the exploitation of geothermal energy of the sea. Also, sea temperature changes occur in predictable and small ranges on an annual basis which makes sea geothermal energy an extremely attractive renewable energy source.

3.8.2. Results analysis and interpretation

The installation of the selected system of renewable energy sources would significantly contribute to the energy independence of the facility, the reduction of greenhouse gas emissions, and the wider social promotion of responsible energy management. This allows the owner of the facility to stand out as a legal entity that takes special care of environmentally friendly development.

The main advantages of a seawater/water geothermal heat pump include:

- the commercially available and developed technology
- possibility of installation due to the proximity of the sea
- significant efficiency of geothermal energy exploitation (COP takes a value between 4 and 5, and EER between 25 and 30)
- low maintenance costs of indoor units
- the possibility of obtaining financial support
- energy independence and the possibility of combined work with other renewable energy systems

The main disadvantages of a seawater/water geothermal heat pump include:

- significant investment cost
- complex installation
- insufficiently defined regulatory framework
- complex maintenance of the underwater part of the system

3.8.3. Overall description of the application

Based on the insight into the current state of the building as well as the existing energy infrastructure and considering the availability and potential of offshore renewable energy sources, it is proposed to implement a thermal envelope on the facade and roof of the building and to replace the existing windows to reduce primary energy consumption while increasing comfort inside the building. Also, it is proposed to build an exploratory well in the ground at a depth of up to 50 m below sea level, which would allow the acquisition of relevant geological data that form the basis for the design and construction of the future seawater/water heat pump. Since an air/water heat pump is already installed in the considered facility, its modification is proposed which would enable the use of seawater as a secondary source of heating and cooling energy.

3.8.4. Economic assessment

The exact economic aspects of the seawater/water heat pump system cannot be estimated at this time given the lack of geological data. However, the estimated investment cost is between 500 and 1,500 €/kW of installed capacity, depending on the design of the heat pump system (passive, active, energy system load). Also, the indicative return of investment is between 5 and 10 years. The duration of the return period can be reduced by obtaining a grant funded by The Environmental Protection and Energy Efficiency Fund of the Republic of Croatia.

3.8.5. Conclusion

The study considered the applicability, feasibility, and economic profitability of the concept of blue energy, and in general the concept of renewable energy sources for the needs of electricity generation, domestic hot water heating, and space heating and cooling. The possibility of implementing a seawater/water heat pump in the context of available offshore renewable energy sources was considered. Basic technical requirements and related constraints are specified. A selection of potential application sites was conducted. Based on the acquired data, a feasibility study was performed with special reference to the recommendations for further implementation, considering economic indicators such as the required investment and the duration of the payback period.

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