ENERCOAST PROJECT

"Renewable energies in the marine-coastal areas of the Adriatic- Ionian region"

Technical, Environmental and Economic analysis of low and medium size of solar cooling systems, heat pumps with sea water, wind turbines and tidal current technologies

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L'Europe en Méditerranée
Europe in the Mediterranean
Projet cofinancé par le Fonds Européen de Développement Régional (FEDER)
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Foreword

ENERCOAST – *Renewable Energies in the Marine-Coastal Areas of the Adriatic-Ionian Region* is a project co-financed under the MED Programme. Its attention is focused on elaboration of the state of art of the renewable energy sector through a deep analysis of the available data and technologies for the exploitation of renewable energy sources in marine-coastal areas, development of technical and non-technical solutions to increase the use of such technologies, in order to contribute to the Blue Growth through a transnational cooperation in the Adriatic-Ionian sub-region.

The MED Programme is an EU transnational cooperation programme among the "Territorial Cooperation Objective" of the EU Cohesion Policy. Project ENERCOAST is selected in the "Integrated Maritime Approach" call for proposals of the MED Programme, under Priority 1: Maritime Innovation and Economic Development; Objective 2: Strengthening cooperation between economic development stakeholders and public authorities.

ENERCOAST partners come from 4 countries (Italy, Slovenia, Croatia, Greece), covering Adriatic-Ionian region are working together to develop technical and non-technical solutions to increase the use of renewable energy in marine-coastal areas of the Adriatic-Ionian region. This kind of cooperation is essential to the achievement of the project and its results, especially to obtain a reliable state of the art regarding the possibility to exploit blue energy in coastal areas with intense tourist activity and port infrastructure, characterised by intense consumption of energy and significant environmental impacts. Also, transnational approach will be used to gather already developed policy and legislation experience in energy sector and blue energy technologies as well as to identify gaps both in data availability and policy framework in the involved countries of the ENERCOAST project.

The specific objective of the ENERCOAST project is to obtain clear proposals on how to contribute to the Blue Growth with emphasis on technical and economic activities of blue energy in the Adriatic-Ionian marine-coastal are such as: solar radiation, wind power, wave and tidal current power and sea water thermal energy to be used in heat pumps. The ENERCOAST main actions consist of:

1. State of the art of the blue energy sector:
   - analysis of the availability and potential of blue energy resources
   - evaluation of the existing installations of the blue energy technologies for exploiting the mentioned sources
   - market analysis of the blue energy technologies usable for the exploitation of the above mentioned resources
   - highlighting the positive and negative environmental impacts of the blue energy technologies
2. Proposals and orientations
   - identification of obstacles and solutions (technical and non-technical) to overcome such obstacles and facilitate the application of above mention blue energy systems
   - elaboration of technical, economic, environmental and legislative orientations and proposals, to be used for the elaboration of future projects

Main target groups of the ENERCOAST project are:

1. Producers of blue energy technologies
2. Local bodies and administration especially small and medium municipalities in the coastal areas of the participating countries
3. Small and medium tourist facilities associations located in the coast and isles of the participating countries
4. Small and medium associations of the services providers (architects, engineers and technicians associations, energy service companies and energy agency) in the participating countries

1. Introduction

This document is the result of the work of all participating partners of the ENERCOAST - *Renewable Energies in the Marine-Coastal Areas of the Adriatic-Ionian Region* project, concerning Action 2: "***Technologies analysis"***, under WP2: **"Technical activities of the project"** for which responsibility has been assigned to the University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture.

The main purpose of the report in the **Action 2** is to elaborate a deep analysis of blue energy technologies: solar cooling, wind energy, seawater heat pumps and marine wave and tidal energy, in order to obtain a complete knowledge of these systems to be applied in coastal-marine areas, with particular attention to their impacts on the environment, and their interrelation with the different activities and sectors. Beside technical information of analysed technologies the report will contain information about existing installation, economic and environmental data as well as a list of available literature for each technology. Above mention technologies were selected for detail analysis after collecting data for existing blue energy installation in partner countries presented in the report "*Final report on existing RES installations in marine-coastal (Adriatic-Ionian) area*". The environmental and legislative information, as well as current status and future targets of renewable energy technologies in partner countries of Adriatic-Ionian region were collected and analysed based on the data collected in the Action 1 under the report "*Final report on legislation, status, targets and barriers of renewable energy utilisation"*.

Part of the Action 2 is also to provide literature review of available studies and reports for blue energy technologies from partner countries as well as on European level. The Literature review will be based on the elaboration of existing data and information, gathered from studies and reports developed and made available first of all by the partners, and then by other institutions such as the Joint Research Centre (JRC), the European Commission and Agencies, local administrations (Regions and Counties), Universities and Research Institutions, previous European projects, and enterprises documents. The literature used in the report is marked with a legend for information which can be found in selected literature. This way the reader will easily find the information from the listed literature and reduce search time for missing information.

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The University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture (Croatia) was the coordinator of the action ensuring quick and smooth implementation. Partners involved in collecting data for preparation of this report were: Italy - Province of Rimini (responsible for wind energy data), Greece - University of the Aegean (responsible for wave and tidal energy data), Italy - Cortea scrl (responsible for heat pumps with sea water data) and Goriška Local Energy Agency Nova Gorica (responsible for solar cooling data). Emphasis has been put on collecting data from available installation in partner countries and each partner was responsible for only one technology. Each partner has worked and provided information on selected technology for its own country based on technology questionnaire. In questionnaires partners collected following:

- Manufacturer data for selected blue energy technology/installation
- Energy and technical data for selected technology/installation
- Environment data for selected technology/installation
- Financial data for selected technology/installation
- SWOT analysis on selected technology/installation

Questionnaire used for data collecting can be found at the end of document in Annexes.

In order to achieve the purpose for the Action 2 this report is divided into 4 technology sections and each technology section consists of short technology introduction, analysis of the operating condition and different technology option and on environmental and economic information for selected technology. Also, examples from the EU and the world are listed with key information about installed capacity and investment cost. At the end of each technology, data sheet with technical, economical and environmental information is presented. Information for data sheets are collected by partners through questionnaires, from literature available on the internet and secondarily on invited expert advice. In order to have consistent and reliable data set for analysed technologies some information in tables are not complete, rather than to use unfounded guesstimates.

2. Seawater heat pump

Heat pumps are devices that move thermal energy from colder, low-temperature point, also called a heat source, to another point at higher temperature, also called a heat sink. Because the heat is transferred in the opposite direction to the natural heat flow (from a high-temperature to a low-temperature point), heat pumps require mechanical work to operate. They are used for industrial purposes, district heat production and individual space heating or cooling.

The basic heat pump system comprises heat source, heat sink, evaporator, compressor, condenser, expansion valve and a refrigerant (Figure 1).

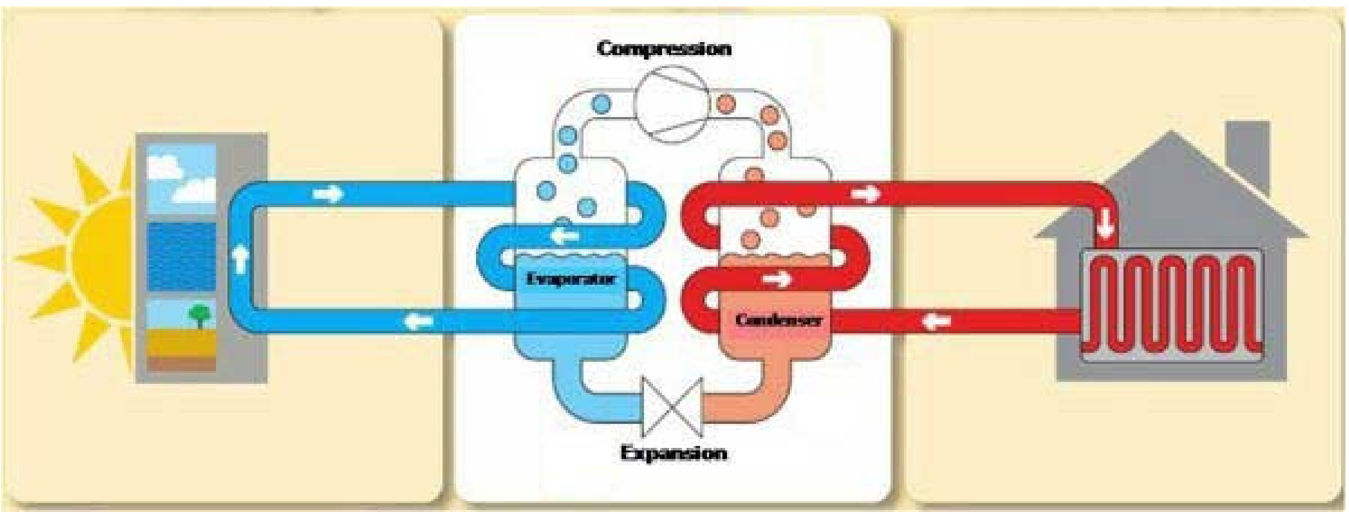

Figure 1: Basic heat pump system [1]

In the beginning of a cycle the refrigerant is in a cold, low pressure, liquid state. Refrigerant is flowing through tubes in heat exchanger called the evaporator, which is exposed to a heat source. Heat source can be air, ground or water (fresh water, sea water, etc.). Because the refrigerant is colder than the surrounding sea water, heat moves from the heat source to the refrigerant and elevates its temperature. As the refrigerant changes from a liquid to gaseous state, a process known as evaporation, the large amount of energy is transferred. Refrigerant exits the evaporator as a warm gas at low pressure and enters the compressor. The compressor raises the pressure of the gas, which also raises its temperature. The hot gas now moves to another heat exchanger called the condenser. The condenser is in contact with water and the

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hot gas now gives up its heat to the colder water. As the refrigerant gives its heat to the cold water, it cools off below its condensation point and changes from a gaseous state to a high pressure liquid state. Cool high pressure refrigerant now flows through the expansion valve and its pressure and temperature are greatly reduced. Refrigerant is now in liquid state and once again ready to absorb the heat from the heat source. This cycle represents a heating mode of a heat pump. When the heat pump is used for cooling, the principle is the same only now evaporator becomes condenser and condenser becomes evaporator.

The efficiency of a heat pump is measured by a parameter called the coefficient of performance (COP). Theoretical COP is given by the equation:

for heating

$$COP = \frac{\text{Heating effect}}{\text{Energy input}} = \frac{T_{hot}}{T_{hot} - T_{cold}}$$

and for cooling.

$$COP = \frac{\text{Cooling effect}}{\text{Energy input}} = \frac{T_{cold}}{T_{hot} - T_{cold}}$$

Both temperatures are given in Kelvin (K = °C + 273.15). For example, with T_{hot} of 75 °C and T_{cold} of 15 °C the theoretical COP for heating is 5.8. It means that for every 1 kW of electric energy used 5.8 kW of thermal energy is produced. From the equation is visible that efficiency will decrease as the outside temperature decreases. In practical appliances the COP will be lower because of the losses in the system. When working in a heat mode, heat pumps are more efficient in use of electric energy than common resistance heaters. Resistance heaters have COP = 1, for every 1 kW of electric energy used they get 1 kW of thermal energy. Today's best heat pumps have the COP between 6 and 7.

The typical capacity of small heat pumps is from 0.5 to 25 kW heat output. The capacity of large heat pumps is from 25 kW to 5 MW heat output. Large heat pumps with a heat output larger than 5 MW are a number of serially connected heat pumps.

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There are many types of heat pumps. Heat pumps are classified regarding to what heat source they are using. Most commonly used are air source heat pumps (ASHP), ground source heat pumps (GSHP) and water source heat pumps (WSHP). Water source for a heat pump can be surface water (e.g. river, lake, sea water) or a ground water.

Table 1: Comparison of different heat pumps based on a heat source used

	Suitability	Availability	Installation cost	O&M cost	Temperature
ASHPs	GOOD	EXCELLENT	LOW	MODERATE	VARIABLE
Vertical GCHPs	MODERATE	GOOD/ EXCELLENT	HIGH	MODERATE	GOOD
Horizontal GCHPs	MODERATE	MODERATE/ GOOD	MODERATE	MODERATE	GOOD/ EXCELLENT
GWHPs	GOOD	GOOD	MODERATE	MODERATE/ HIGH	GOOD/ EXCELLENT
SWHPs	GOOD	MODERATE	MODERATE	MODERATE/ HIGH	GOOD

Most of the solar heat energy reaching the Earth is absorbed directly into the ocean or indirectly in fresh water. A key feature that makes sea water excellent as a heat source is its relatively constant temperature over the year. The heat capacity of water is higher than that of air, which makes the water more difficult to heat up or cool off than air. In the example of Rijeka, Croatia (Figure 2.) we see relatively little oscillation of sea temperature in the heating period (27th October 2008 to 14th April 2009).

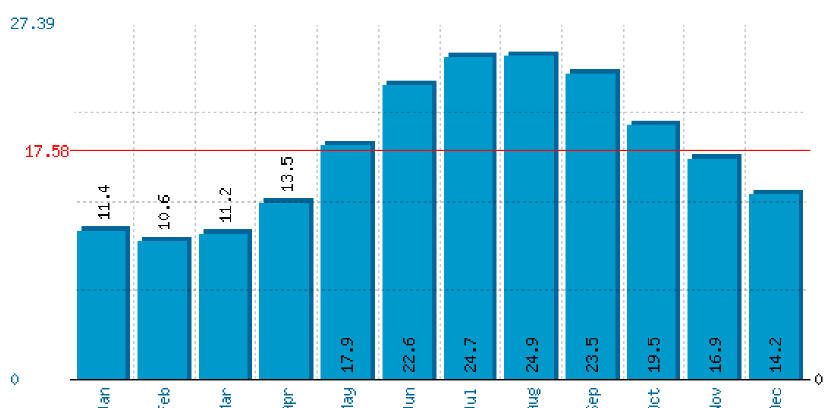

Figure 2: Sea temperature [°C], Rijeka, Croatia [2]

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In the example of Anchorage, Alaska (Figure 3.) the temperatures are lower, but still relatively constant through the heating period which is longer than in the case of Rijeka. Ice formation in the northern areas is not a problem because of salinity, the freezing point of sea water is from -1 to -2 °C.

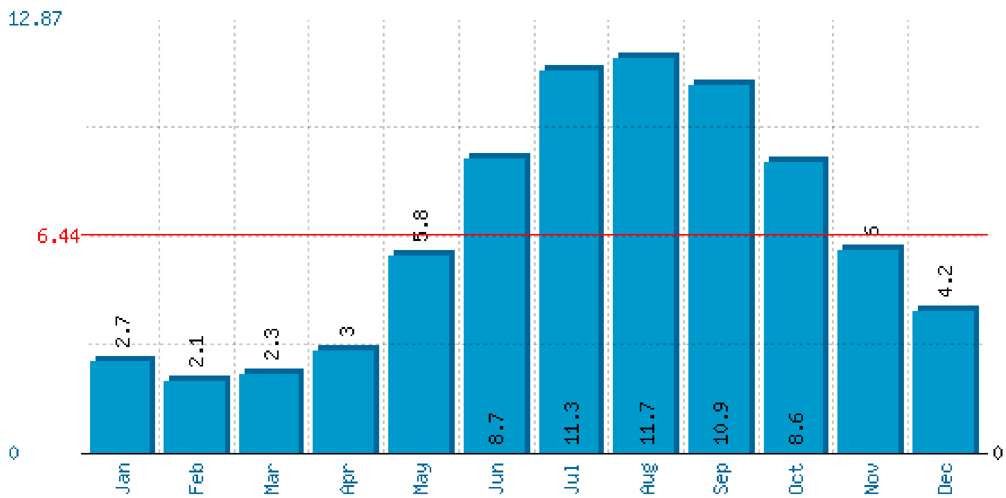

Figure 3: Sea temperature [°C], Anchorage, Alaska [2]

In case of Dalian, China (Figure 4.) we can see that the sea water temperature is almost always higher than the outdoor air temperature.

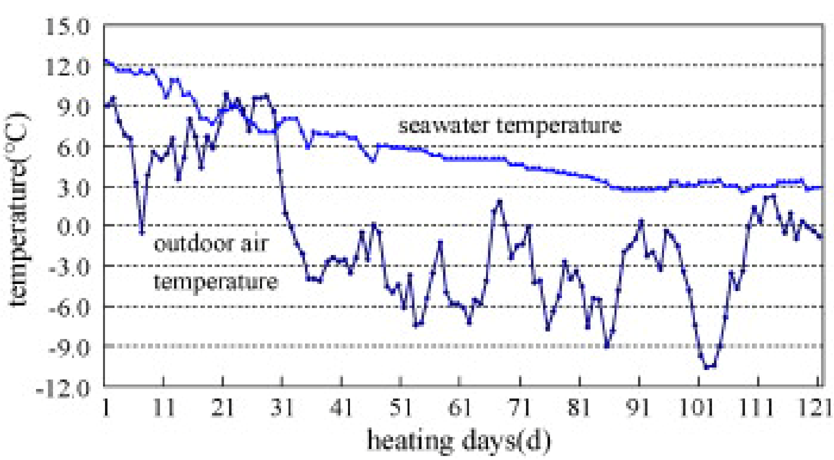

Figure 4: Comparison of sea and air temperature [3]

Based on the equations given before, we can assert that the water source heat pumps are generally more effective and will have a higher COP than the air source heat pumps. Sea water as a source is mainly used in medium-sized and large heat pump systems. Traditional district heating plants that burn fossil fuel to produce hot water or steam for heating can be replaced with modern district heating plants that use seawater heat pumps. This type of system is ideal for application in colder climates where the air temperature drops deep below zero. Example is Seward, Alaska in which they replaced the old heating system with the seawater heat pump system. The seawater heat pumps also allow heating at low to medium temperatures, which eliminates dangerous steam lines and high energy losses. On the other side, heating at low to medium temperatures, encourages and increases the investment in energy efficiency of buildings (low temperature heat distribution system, envelope efficiency).

There are two basic categories of heat pump systems, open-loop and closed-loop (Figure 5.).

In an open-loop system the water from the water source (e.g. ocean, river, lake or groundwater) is pumped through a heat exchanger in one place and discharged to the same or another point. This type of system can be cheaper than the closed-loop system, because their installations involve less work. The efficiency of the open-loop system can be same or higher than the closed-loop systems. Codes and regulations regarding water source must be met. To ensure uninterrupted operation and long service life of a heat pump, consistency of the water supply concerning quantity and quality are crucial. The open-loop system is limited for application in cold climates due to freezing temperatures that can make the water sources unavailable or cause water pipes to freeze.

A closed-loop system consists of a pipe loop placed in the ground or water. Fluid with low freezing point (e.g. glycol-water) circulates through this loop. This type of system is more expensive than the open-loop system because of expensive drilling. Due to open-loop system limitations they are more common. The closed-loop system reduces the risk of freezing and requires almost no maintenance. These types of systems are more susceptible to damage and they can be potentially dangerous for the environment because if the fluid escapes the loop it can contaminate water or ground. Length of the pipe loop depends on the site and the heating capacity of heat pumps. Pipe loop can be vertical or horizontal (Figure 5.).

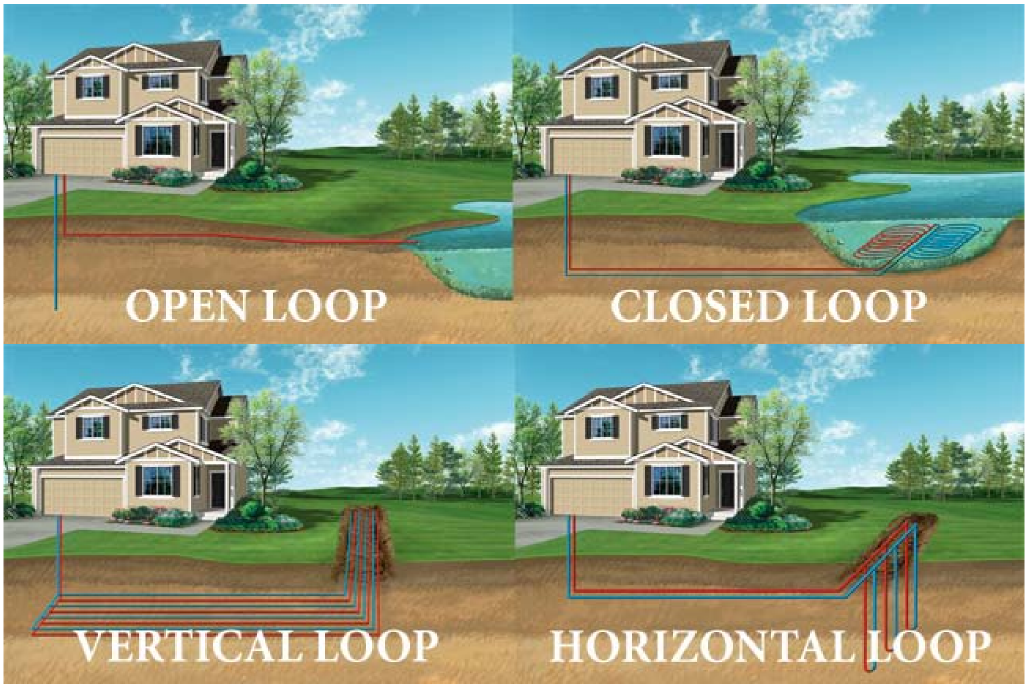

Figure 5: Various types of heat pump systems [4]

Another successful example of using a district heating system with seawater heat pump is in Drammen, Norway. The capacity of the system is 14 MW. The average annual supply of energy is 67 GWh. Sea water is taken from a depth of 18 m with the temperature around 8 or 9 °C. It heats the water from 65 to 90 °C for heating or hot water systems. The average COP of a system is around 3.0. Combined with low cost of electricity produced by hydro power plants it is a cheaper solution than a gas or electric boiler. It is the world's largest district heating system with seawater heat pumps.

Practical application of seawater heat pumps in the southern areas can be seen in Split, Croatia. The seawater heat pump system is used both for heating and cooling of an apartment building with useful area of 520 m^2. The heating capacity of the heat pump is 17 kW. The average sea water temperature is 13 °C. The apartment building is located near the sea, therefore it was an ideal choice for a heat source. Heating and cooling system is regulated completely automatically. The COP in the heating mode is 5.5 and the energy efficiency ratio (EER) in passive cooling is from 25 to 30.

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Another important part of the heat pump system is a refrigerant or a process fluid. Over the last decades of the 20th century Freon-based refrigerants were used. They were efficient, stable and cheap, but they were environmentally unfriendly. They caused the depletion of the ozone layer. Market agreed that something had to be done and they decided to phase-out those gases and developed refrigerants which are not ozone depleting. These refrigerants are hydrocarbons (e.g. propane, butane, iso-butane), ammonia, water and carbon dioxide. It is important to note that the usage of these refrigerants does not decrease energy efficiency of heat pumps.

One major problem with the seawater heat pump systems is the corrosion of pipes transporting sea water. Normally sea water is more corrosive than fresh water. Due to the higher corrosiveness of sea water the pipes of seawater heat pump systems are made from special materials like titanium alloys or copper alloys. These materials are more resistant to corrosion (galvanic currents) which on the one side increases the lifetime of the system, but on the other side raises investment and O&M costs.

Seawater heat pumps are efficient and clean machines which can provide heating, cooling or hot water supply to buildings, residential or commercial. In the European Union, Japan, Australia, the United Kingdom and the United States they are considered as a renewable energy and these states grant many benefits to use heat pumps. Other countries have not recognized the potential of heat pumps and their contribution to reduce CO_2 emissions and global warming effect. Today's need for heating, cooling and hot water is estimated to be roughly half of the total energy consumption in buildings. The largest amount of that energy demand is still met by burning fossil fuels, which are related to CO_2 emissions. In order to meet these two requirements, lowering CO_2 emissions and growing energy need, implementing seawater heat pumps in residential sector and district heating systems can be a solution.

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2.1 Technology data sheet – Seawater heat pump

small scale application (< 100 kW)				
Energy / Technical data				Ref
Heating capacity per unit [kW heat]		10 - 80 kW		17,18,20
Cooling capacity per unit [kW cooling]		10 - 60 kW		18,20
Coefficient of performance EER		3 - 5.5 25 - 30		5,17,18,20
Operating temperature +-°C		Heating: 40/65 °C Cooling: 12/7 °C		19,20
Utilisation time [hours/year] or Average annual plant capacity factor		compressor: 700 - 1500 h/y pump: 5500 - 6500 h/y Power: 20 - 30 kW		20
Technical lifetime [years]		7 - 30 years		15
Construction time [days]		20 - 60		5,20
Environment				
Refrigerants		R407c		15,16,20
Financial data				
Specific investment, total costs [€/kW heat out]		500 - 2200 €/kW		15,16,17,20
Operating and maintaining costs [€/kW heat out]		20 - 80 €/kW		15,20
Cost structure				
Investment, capital costs				
	Share of total costs [%]			
Heat pump	30 - 40			20
Pipe connection	15 - 25			20
Other costs	40 - 50			20

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2.2 Seawater heat pump bibliography

Legend:

Technical information on technologies

Economical information on technologies

Environmental information on technologies

Legislative information on technologies

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3. Solar cooling technology

Solar air conditioning refers to any air conditioning (cooling) system that uses solar power, which can be done through passive solar, photovoltaic conversion or solar thermal energy conversion. Key applications for this kind of technologies are those that require low temperature heat, such as domestic water heating, space heating, pool heating, drying process and certain industrial processes. Solar applications can also meet cooling needs, with the advantage that the supply, which is on sunny summer days, and the demand, which is desired for a cool indoor environment are well matched. The comparison of cooling and heating demand and solar radiation by month can be seen on the graph below (Figure 1).

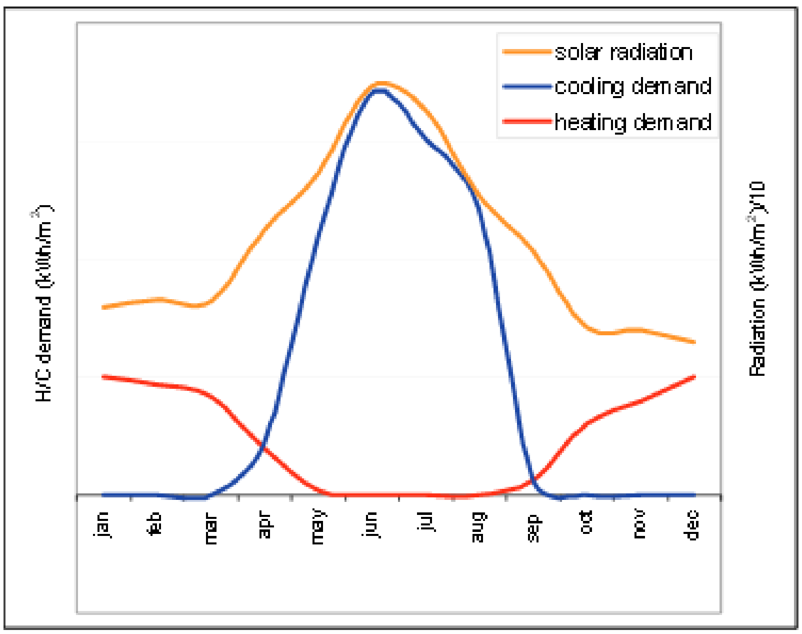

Figure 1: Comparison of cooling and heating demand and solar radiation by month [1]

Using solar energy for cooling purposes is quite a new technology and it is growing rapidly. Progression of new documented and estimated installations of solar cooling systems worldwide by year is shown in Figure 2. The main goal of applying solar energy for cooling buildings is to reduce the energy consumption and to make this task more environmentally friendly. It can also reduce air-conditioning and industrial cooling costs. Solar cooling systems use concentrated or vacuum solar collectors and absorption chillers to drive the cooling process and these systems are ideal for cooling hotels, office buildings and other commercial buildings. The same collectors

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can also heat water for the facility. Concentrating solar collectors use mirrors to focus the Sun's energy onto a tube containing fluid. The mirrors are following the Sun and they are heating the fluid to very high temperatures. The absorption chiller is a machine that uses a heat source to generate chilled water rather than an electrical source that is used in the vapour compression cycle. There are multiple alternatives to compressor-based chillers that can reduce energy consumption, which reduces noise and vibrations. There are single, double or triple iterative absorption cooling cycles that are used in different thermal cooling system designs and with more cycles the systems are more efficient.

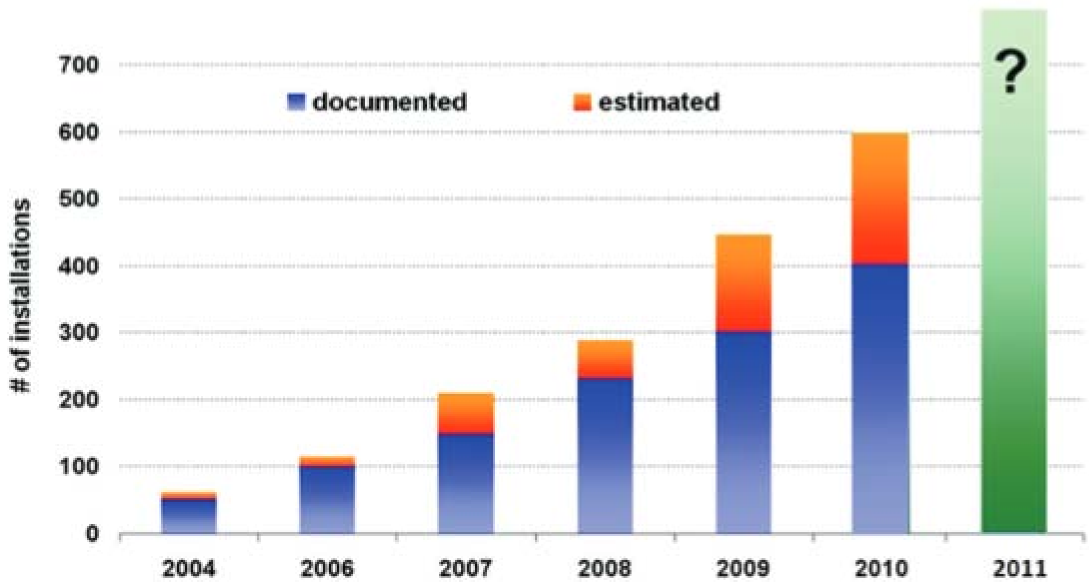

Figure 2: Documented and estimated installations of solar cooling systems worldwide [2]

There are two main solar cooling processes:

1. Closed cycle - thermally driven sorption chillers produce chilled water, which can be used in space conditioning equipment
2. Open cycle – also known as desiccant evaporative cooling systems (DEC), which use water as the refrigerant and a desiccant as the sorbent for direct treatment of air.

There are many advantages over alternative solutions:

- Solar thermal cooling can help reduce electricity peak demand for conventional cooling because cooling is usually most needed during maximum solar radiation.

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- It can also work in the evening hours because it has thermal storage.
- After summer the solar cooling system can be used for heating purposes, such as space heating and preparation of domestic hot water.
- In the Mediterranean regions with high solar gains and high cooling demands solar cooling could become an alternative to conventional cooling systems.
- The applicability of thermal energy as driving energy.
- Low electrical power rating.
- Durability and environmental compatibility.

But it also has its disadvantages:

- They still have high installation costs.
- Space requirements for heat storage.
- Necessity of an additional backup system.

The total costs of solar cooling kits by its cooling capacity are presented in Figure 3. There is a huge difference in cost between solar cooling kit with integrated solar collectors and without.

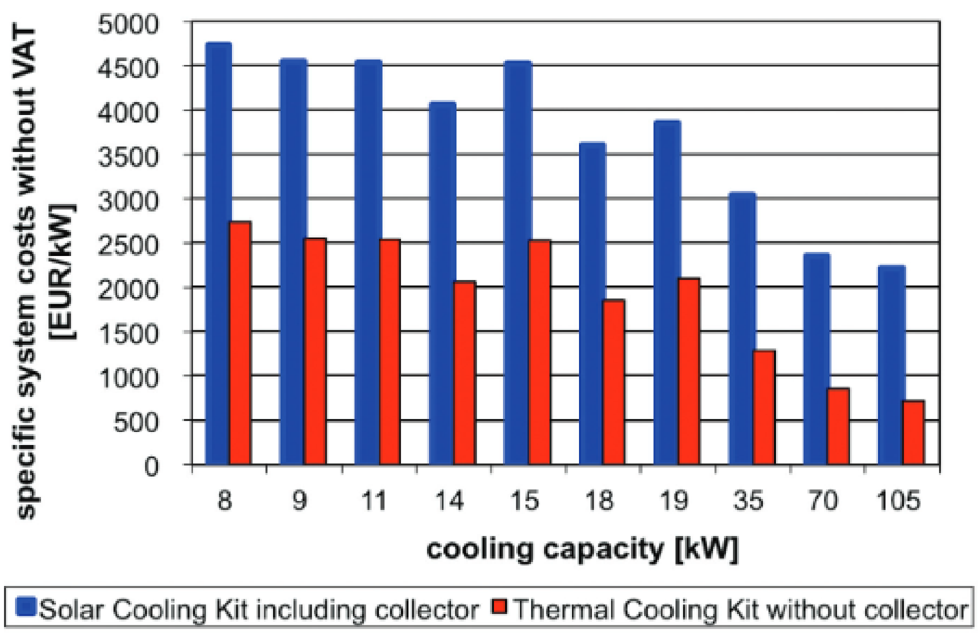

Figure 3: Specific total costs of solar cooling kits by its cooling capacity [2]

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Generally, two solar cooling concepts are possible:

a) Cooling with PV system

The Photovoltaics can supply the power for any type of electrically powered cooling whether it is conventional compressor-based or adsorption/absorption-based. The most common (conventional) implementation is still with compressors. The PV-powered cooling has been the most frequently implemented solar cooling system for small residential and small commercial cooling with less than 5 MWh/a. The reason for this is the lack of residential-sized equipment for other solar-cooling technologies and easier installation of the PV systems compared to the other solar-cooling technologies. The schematic view of solar cooling with PV module is shown in Figure 4.

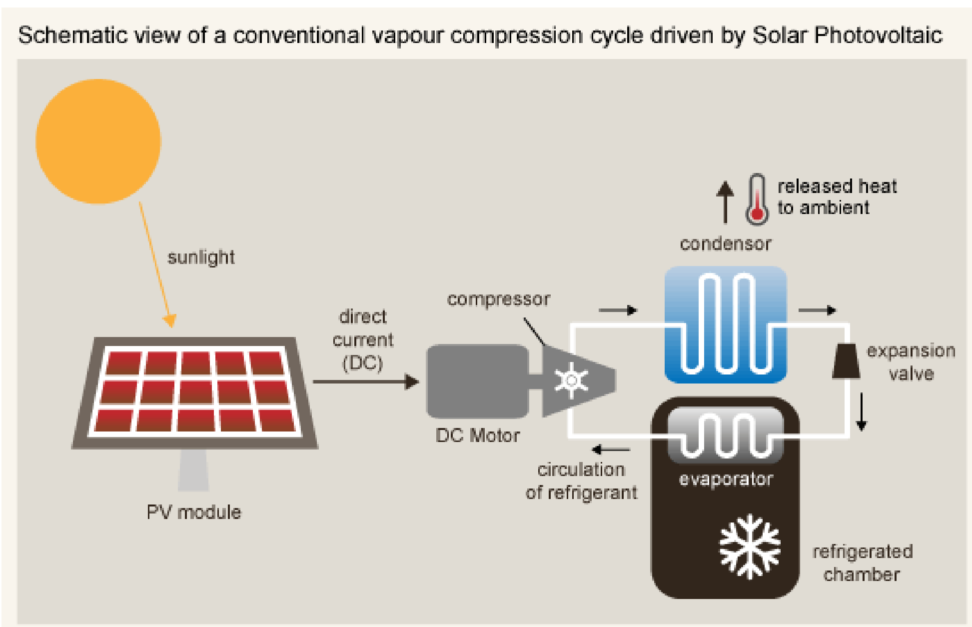

Figure 4: Scheme of solar cooling with PV module [3]

b) Cooling with thermal collectors

Solar assisted cooling systems usually need solar thermal collectors connected to thermally driven cooling devices. They consist of several crucial components:

- Solar collectors

- Heat buffer storage
- Air conditioning subsystem with various forms of cold distribution
- Backup subsystem

There are three thermal driven systems:

a. Absorption cooling with chilled water

Absorption chillers powered by solar energy use hot water from solar collectors to absorb already pressurized refrigerant from an absorbent/refrigerant mixture. It can be water/lithium-bromide and ammonia/water. Condensation and evaporation of the refrigerant vapour have the same cooling effect as mechanical cooling systems. Absorption chillers require some electricity from the grid for pumping the mixture, but the amount is very small compared to electricity that is consumed by a compressor in a conventional electric air conditioner. Absorption chillers are the most widely used chillers in the world. Most of the installations are located in Europe, China and the Middle East. Schematic view of the absorption solar cooling system can be seen in Figure *5*.

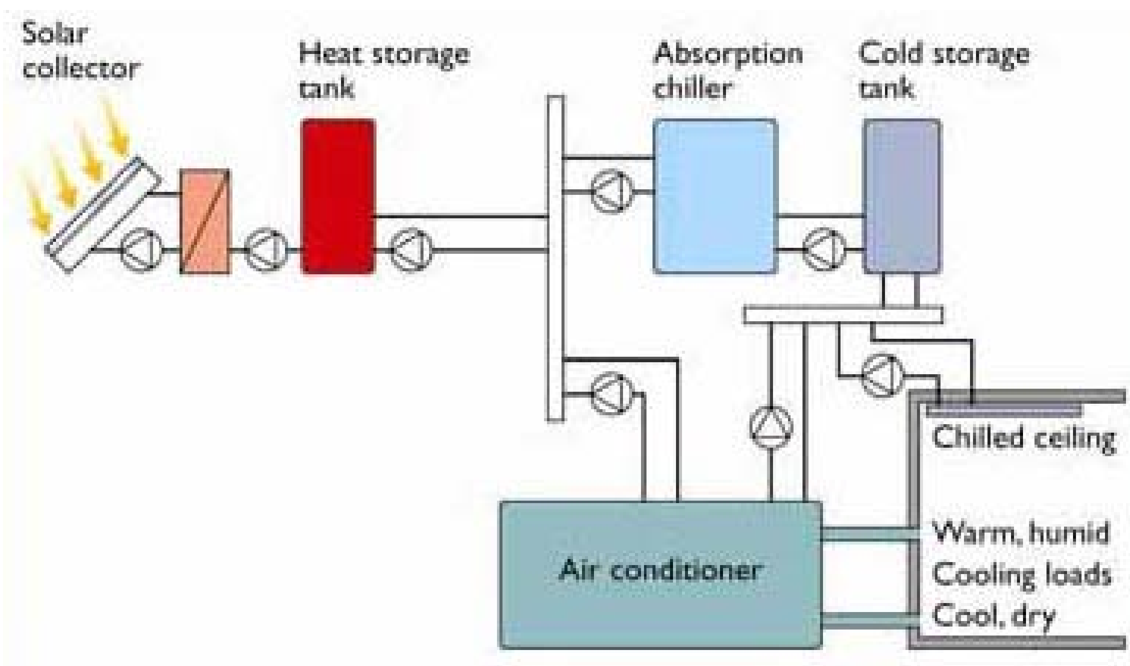

Figure 5: Scheme of an absorption solar cooling system [4]

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b. Adsorption cooling with chilled water

Instead of a liquid solution this system uses solid sorption materials. Systems use water as a refrigerant and silica gel as a sorbent. The machine has two sorbent compartments, one evaporator and one condenser. The capacity of the chillers ranges from 50 to 500 kW. Under normal operation conditions, with a driving heat temperature at about 80 °C, the systems can achieve a thermal COP of about 0.6. Operation is possible even at a heat source temperature of 60 °C. Its advantage is a simple mechanical construction of adsorption chillers and their expected robustness. There is no danger of crystallization and because of that no limitations exist in the case of the heat rejection temperatures. There is no solution pump so only a minimum of electricity is consumed. One main disadvantage of this system is that they are heavier compared to absorption systems. Schematic view of the adsorption solar cooling system can be seen in Figure 6.

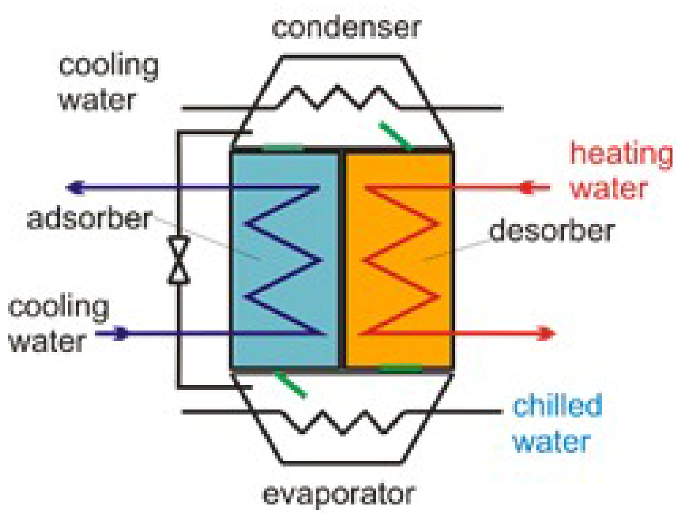

Figure 6: Scheme of an adsorption solar cooling system [5]

c. Desiccant cooling for air based cooling systems

Desiccant cooling systems are open cycle systems, which use water as a refrigerant that is in direct contact with air. The cooling cycle is a combination of evaporative cooling with air dehumidification by a desiccant. Liquid or solid materials can be used as a desiccant. Since there is a direct contact with the atmosphere only water is possible as a refrigerant. Rotating

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desiccant wheels, which are equipped with silica gel or lithium-chloride as sorption material, are commonly used today.

Advantages of this system are: increased comfort, lower operating costs, heat recovery options, improved indoor air quality and reduced building maintenance as a result of high humidity levels. Desiccant systems directly produce conditioned fresh. The schematic view of air based cooling system with desiccant cooling can be seen in Figure 7.

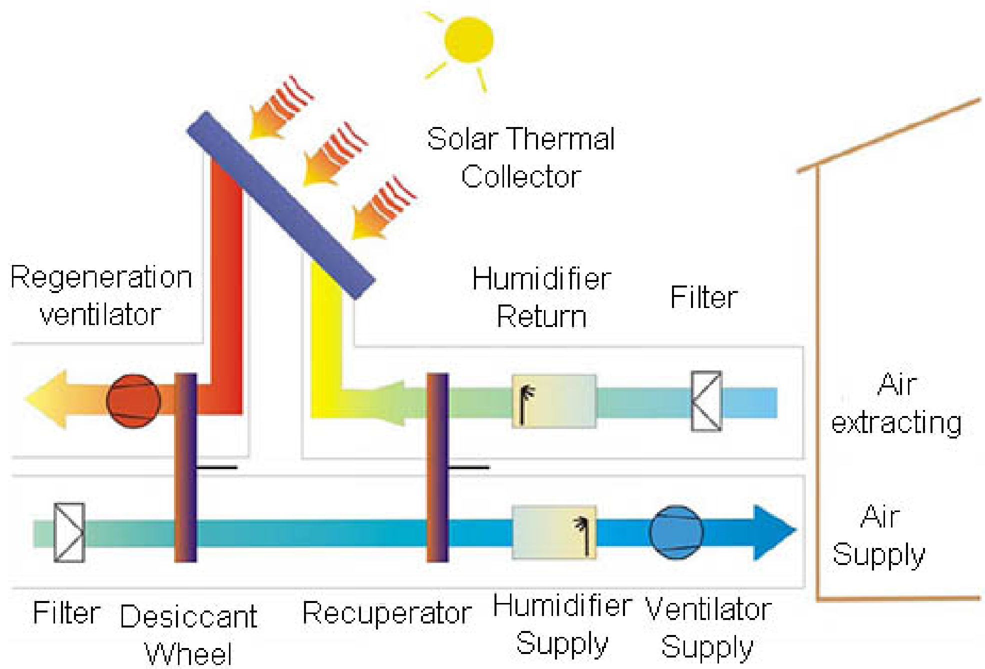

Figure 7: Scheme of an air based cooling system with desiccant cooling [6]

For cooling systems above 40 kW there are different heat driven cooling technologies available on the market, which can be used in combination with solar thermal collectors. The main problem for large scale applications, except the high capital cost, is the lack of practical experience and knowledge among builders and planners with the design, control and operation of these systems.

The main technologies for cooling systems under 30 kW cooling loads are absorption and adsorption technologies. Many new sorption chillers with small-scale and medium-scale cooling capacity have been developed in Europe. The solar cooling systems contain solar thermal collectors with hot water storage, pump-sets, chiller, re-cooler, partly cold water storage and a

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control unit. The specific total costs of installed solar cooling systems in Europe in 2007 were between 5,000 and 8,000 €/kW.

Successful examples of using cooling systems can be found throughout Europe, especially in the Mediterranean countries. One of the examples is the public library in Mataro, Spain. The system is a desiccant cooling system with air as the only heating and cooling fluid. The unit is connected to a PV-solar air heating system. During the summer desiccant cooling system with thermal solar energy is used to regenerate the system. During winter, the system is using a heat recovery wheel where thermal solar energy is indirectly used for heating. The next example is also located in Spain in Guadeloupe. A solar assisted cooling system with an absorption chiller was installed there. The installed chiller (30 kW) is driven by vacuum tube solar collectors, and it is connected to a water-based open cooling tower. In Greece, a medical centre has successfully installed the solar thermal system consisting of a water-lithium-bromide absorption chiller, cooling tower refrigeration, solar field collector, hot-cold water storage tank, control system as well as a backup system. In the past years, Slovenia had installed various solar cooling systems that range from 20 kW to 250 kW cooling capacity.

Currently, the largest market for solar thermal collectors in Europe is Germany. In southern European countries, except Greece, the use of solar thermal collectors has been limited in the past. However, in recent years collector sales have been increased dramatically.

The solar heating and cooling technologies in general do not have controversial side-effects such as visual impact and noise pollution. Few countries still have regulations, saying that solar collector must be placed on the roof. However, it is often not the collector that is considered as the problem, but rather the thermal storage above it.

3.1 Technology data sheet - Solar cooling

absorption solar cooling small scale application (< 70 kW)				
Energy / Technical data				**Ref.**
Cooling capacity [kW]			12 - 37 kW	29,9,36
Heating capacity [kW]			40 kW	29
Chilled-hot water	Temperature (cooling)	Inlet [°C]	6 - 35 °C	29,36
		Outlet [°C]	7-45 °C	29,36
	Temperature (heating)	Inlet [°C]	47 – 50 °C	29
		Outlet [°C]	55 – 60 °C	29
	Maximum operating pressure [kPa]		400 – 600 kPa	29
Cooling water	Temperature	Inlet [°C]	20 – 30 °C	29,36
		Outlet [°C]	25 - 35 °C	29,36
	Maximum operating pressure [kPa]		400 – 600 kPa	29
	Heat rejection [kW]		43 - 170 kW	29
Heat medium	Heat input [kW]		25 - 100 kW	29
	Temperature	Inlet [°C]	75 - 88 °C	29,36
		Outlet [°C]	69 - 83 °C	29,36
		Range [°C]	Max. 35 °C	29,36
	Flow rate [l/s]		1 – 5 l/s	29
Electricity	Consumption [W]		50 – 1,000 W	29,36

Environment data		
Noise level [db]	n/a	
Financial data		
Specific investment, total costs [€/kW]	1,300 – 10,000 €/kW	29,36
Operating and maintaining costs [€/kWh]	0.07 - 0.09 €/kW	29
Cost structure		

Investment, capital costs			
	Share of total costs [%]		
Cooling units, ex works	20 - 40		29
Foundation	1 - 5		29
Electric installation	2 - 10		29
Piping and storage	10 - 40		29
Solar collectors	25 - 40		29
Design	2 - 5		29

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Legend:

Technical information on technologies (yellow)

Economical information on technologies (orange)

Environmental information on technologies (green)

Legislative information on technologies (red)

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4. Wind power plant

Wind power plant converts kinetic energy from the wind into electrical power. Wind energy is clean and renewable energy that, unlike fossil fuels, produces no greenhouse gas emissions. Wind power plants cause fewer effects on the environment than those from conventional power sources.

A wind power plant consists of a wind turbine, generator, devices for controlling the operation and buildings for their installation and maintenance (Figure 1).

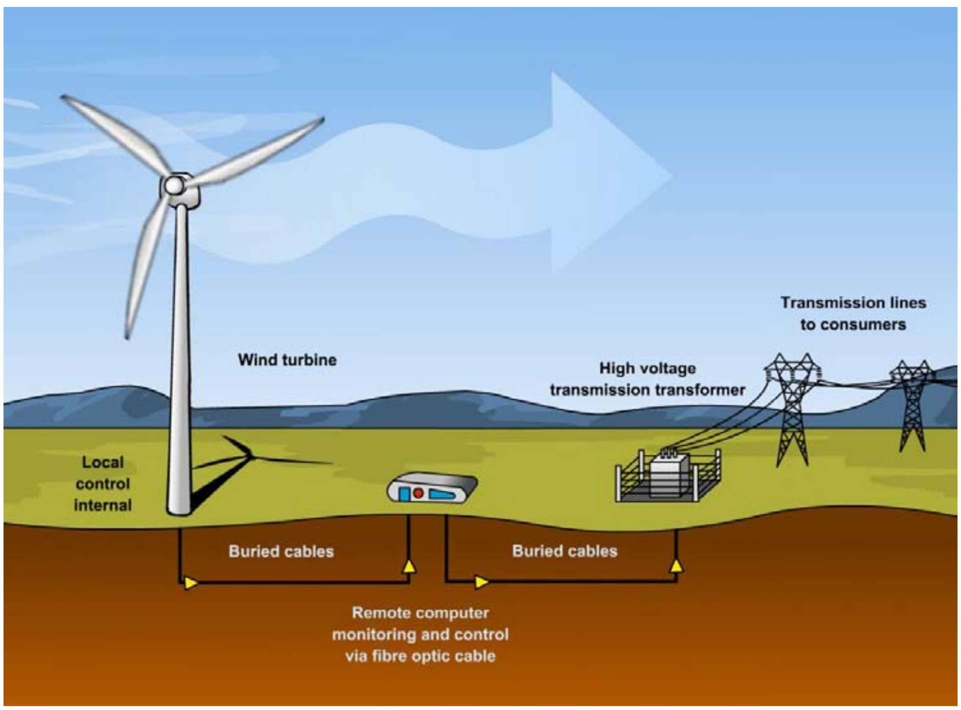

Figure 1: Wind power plant [1]

Wind turbines use aircraft wings shaped blades which are mounted on a central shaft. The force of the wind rotates the blades, converting the kinetic energy of wind into mechanical energy of the rotating shaft. This shaft turns a generator that produces electricity. Some wind power plants are not used for electricity production so the mechanical energy of the rotating shaft is used, for example to operate a mechanical pump or grinding mill. To operate efficiently a wind turbine must be located in an area with high average wind speeds and minimal turbulence. By Bernoulli's equation the speed of the wind increases with higher altitude, so turbines are

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mounted on tall towers to use more kinetic energy of the wind. Wind speed can significantly vary with location, season of the year and field configuration like trees and buildings. The wind is often stronger and its speed is less variable over the sea, so a growing number of wind farms have been built offshore, but unlike the onshore wind farms the construction and maintenance costs are increased.

Wind turbines can rotate about either a horizontal or a vertical axis (Figure 2).

Horizontal axis wind turbines (HAWT) are the most common types of wind turbines. Their main rotor shaft and electrical generator are mounted on top of the tower and must be pointed into the wind. Minimum required wind speed to drive an electrical generator is about 3-5 m/s. Large wind turbines often use a wind sensor in combination with servo motor for adjusting the blades to the direction of the wind, which results in maximum use of the wind. The rated output of wind turbines is electrical power produced at a standard wind speed, which is about 10-15 m/s. The wind doesn't blow all the time at this speed so the average power generated is about 30% of the rated power and this is termed as the capacity factor. In case when wind speed is over 25-30 m/s wind turbine shuts down by rotating blades vertically to wind direction in order to prevent breakdowns caused by oversized wind speed. The lifetime of a wind turbine is estimated to 20 years, but with good maintenance it can extend to 25 years.

Vertical axis wind turbines (VAWT) have the main rotor shaft positioned vertically. Advantages of vertical axis wind turbines are that the turbine does not require to be pointed directly into the wind to be effective and they have a generator and gearbox placed near ground so they are more accessible and easier to maintain. On the down side, they have a shorter lifetime and lower efficiency than horizontal axis wind turbines.

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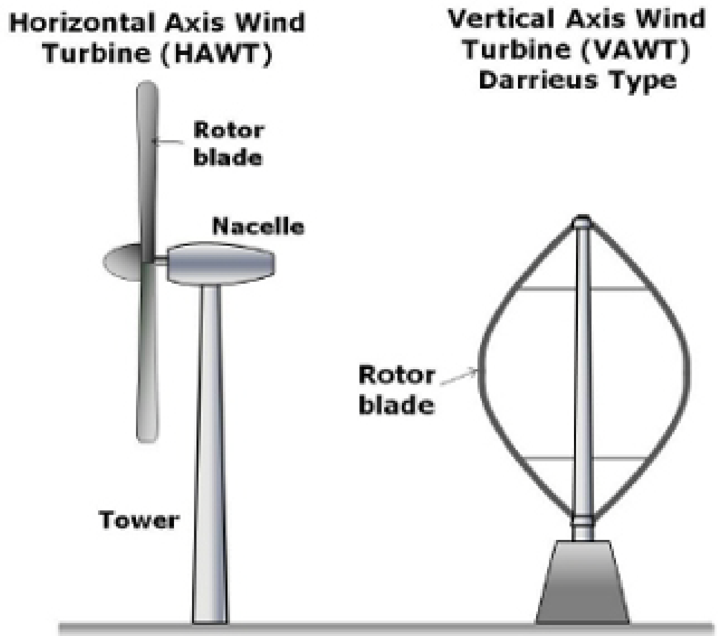

Figure 2: Wind turbine configurations [2]

Most wind turbines supply electricity to national grid, so the produced electricity must be at the right voltage and frequency. Older versions of wind turbines used a gearbox to combine the shaft with a faster rotating generator (Figure 3). Nowadays, advanced turbines use variable speed generators coupled with electronics to feed power to the grid at the correct frequency, allowing the turbine to rotate at ideal for the wind conditions.

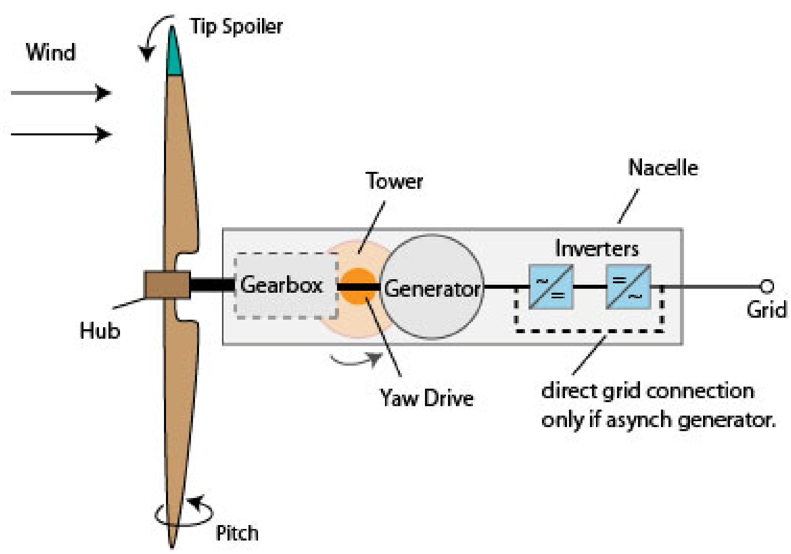

Figure 3: Wind power generator [3]

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Most wind turbines connected to a grid are installed in groups or 'wind farms'. Installing a large group of wind turbines at one location reduces operating and installation costs, but they are not entirely 'eco-friendly'. Wind turbines disturb the landscape appearance and produce a lot of noise. Some ecologists will say that wind turbines also kill a lot of birds, so they have an environmental impact. Modern wind turbines have no gearbox so they produce less noise and they can be installed on sites closer to villages and towns.

Wind energy emits no toxic substances such as mercury and air pollutants nitrogen oxides, acid rain-forming sulphur dioxide and particulate deposits. These pollutants can cause cancer, heart disease, asthma and other respiratory diseases and they can also acidify terrestrial and aquatic ecosystems. Wind energy creates no waste or water pollution. Given the fact that water shortage is a pressing issue and will become even worse with climate change and population growth, wind energy is the key to preserving water resources. Unlike fossil fuels and nuclear power plants, wind energy has one of the lowest water consumption footprints. The principal advantage of wind energy for water-stressed areas is its very low consumption of water in comparison with thermal generation. This is already an important issue in China, and a growing concern in India, as well as in the OECD member countries such as the (western) United States of America. But the greatest benefit of wind power is its contribution to the reduction of carbon dioxide emissions from the power sector, which is the single largest contributor to the global climate change problem.

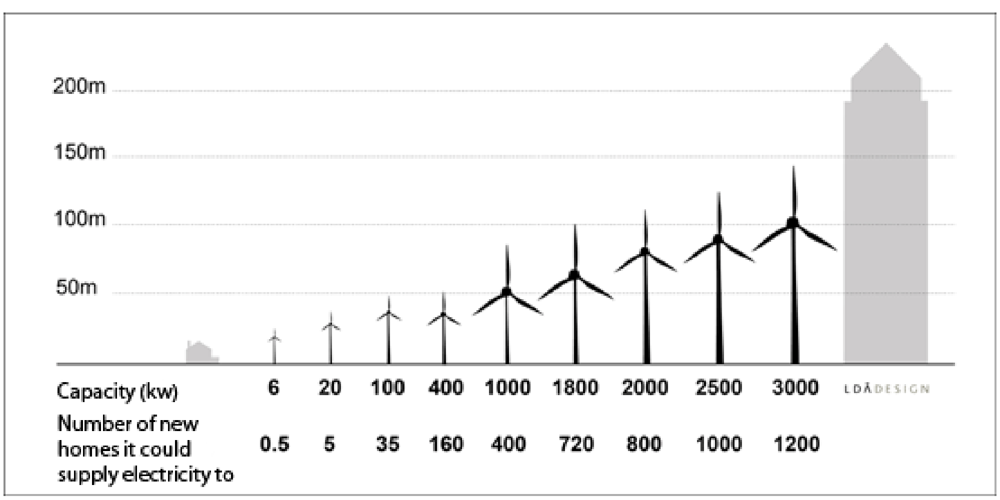

Figure 4: Capacity and size of wind turbine [4]

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Wind farms can be located on land and they are called onshore wind farms, while those located out at sea or in fresh water are called offshore wind farms.

Onshore wind farms

The unrestricted technical potential estimation of the wind potential on land is based on wind power density and wind turbine technology development per type of land cover. All types of land are included, independent of their suitability for wind turbine development. In fact, in countries where wind energy development is quite high (i.e. Denmark, Germany and the Netherlands), the agricultural land areas are the most attractive sites for wind energy deployment. Installation of wind turbines on agricultural land can be very well combined with agricultural uses such as farming or keeping livestock.

Only a limited number of wind farms are installed in mountainous areas. Lower accessibility of mountainous areas and the limited roads and grid connections result in less favourable conditions for wind farms. However, there are wind turbines at high altitudes like in Switzerland or France. Today onshore wind power plants are installed on remote locations, usually away from populated sites.

Offshore wind farms

Offshore wind farms are at the beginning of their commercial deployment stage. They have higher capital costs compared to onshore wind farms. The most important difference between onshore and offshore wind farms are the foundations required for offshore wind turbines. They are more complex structures, involving greater technical challenges, and must be designed to survive the harsh marine environment and the impact of large waves. All these factors and especially the additional costs of installation mean they cost significantly more than land-based systems.

Finally, offshore wind farms will allow a much greater development of wind in the long term. The reasons for the higher capacity factors and greater potential development are:

- Taller and have longer blades, which results in a larger swept area and therefore higher electricity output.
- Sited in locations that have higher average wind speeds with low turbulence.
- Very large wind farms are possible.
- Less constrained by many of the sitting issues on land. However, some constraints exist and they may be just as problematic and need to be adequately considered (e.g. shipping lanes, visual impact, adequate onshore infrastructure, etc.).

Small wind turbines

Small wind turbines are generally considered to be those with generation capacities of less than 100 kW. These smaller turbines can be used to power remote or off-grid applications such as homes and farms. Intermediate-sized wind power systems (100 kW to 250 kW) can power a village or a cluster of small enterprises and can be grid-connected or off-grid. These turbines can be coupled with diesel generators, batteries and other distributed energy sources for remote use where there is no access to the grid. They can play a very important role in rural electrification schemes in off-grid and mini-grid applications. They can be a competitive solution for off-grid electrification and can complement solar photovoltaic systems in off-grid systems or mini-grids.

Almost all current small wind turbines use permanent magnet generators and they are direct drive with two to three blades. Some turbines use four to five blades to reduce the rotational speed and increase the available torque. The height of the tower is also an important factor for small wind turbines. Low towers will have low capacity factors and often expose the turbines to excessive turbulence. Tall towers help avoid these issues, but increase the cost significantly compared to the turbine cost.

There are many criteria which small wind turbines have to fulfil and key features are:

- They are less affected by turbulent air than standard horizontal-axis wind turbines.
- They have lower installation costs for the same height as horizontal-axis wind turbines.

- They require lower wind speeds to generate electricity, which increases their capacity to serve the areas with lower than average wind speeds.
- They rotate at one-third to one-quarter the speed of horizontal-axis turbines, reducing noise and vibration levels, but at the expense of lower efficiency.

As shown in Figure 5, the biggest rate of installed capacity from 2006 to 2014 was in Asia and Europe, but North America is also a growing region.

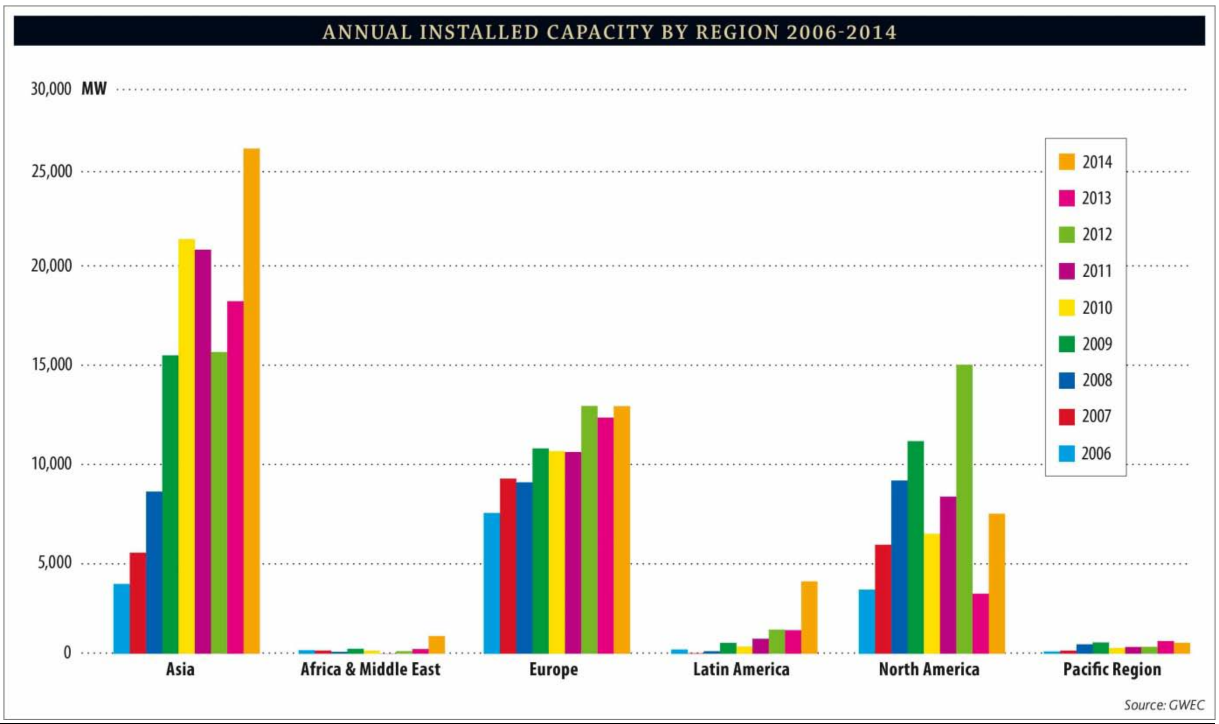

Figure 5: Annual installed capacity by region 2006-2014 [5]

<u>Environmental effects</u>

The environmental impact of wind power compared to the environmental impacts of fossil fuels is relatively minor. Wind turbines have some of the lowest global warming potential per unit of electrical energy generated, having a median value of 11-12 grams of CO_2 by kWh of generated electrical energy.

Modern wind turbine systems have a net energy gain. During their service life they produce more energy than is used to build the system. Any practical large-scale energy source must produce more energy than it is used in its construction. The energy return on investment (EROI)

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for wind energy is equal to the cumulative electricity generated divided by the cumulative primary energy required to build and maintain a turbine. According to a meta study, which reviews all existing studies from 1977 to 2007 the EROI for wind ranges from 5 to 35. Most common turbines in the range of 2 MW and with a rotor diameter of 66 meters have EROI averages 16 (Figure 6.).

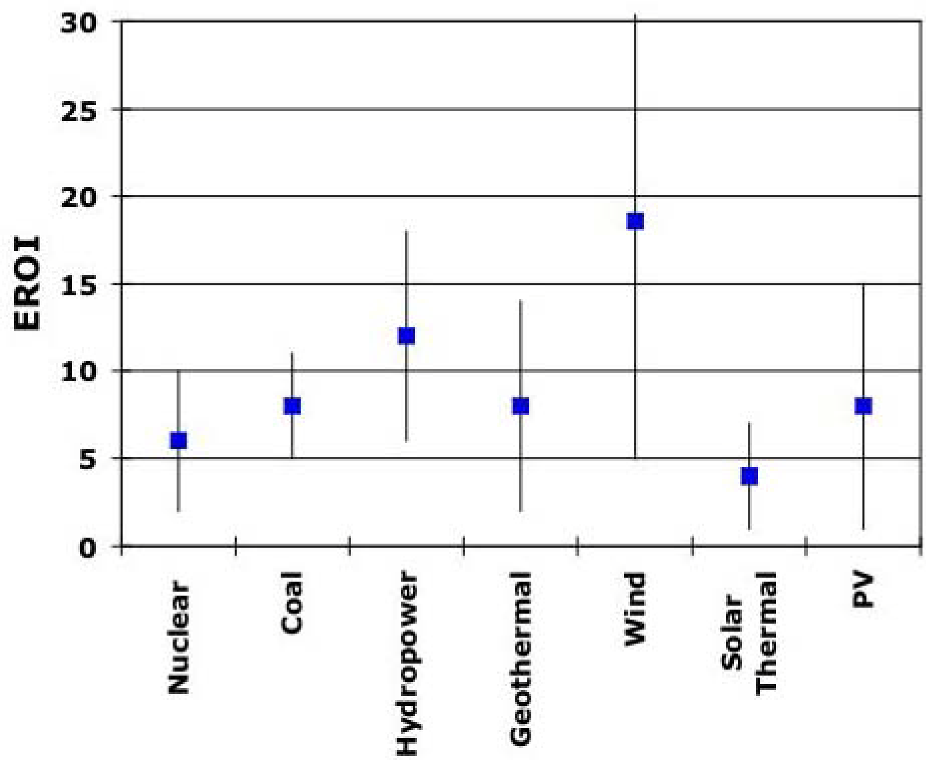

Figure 6: Technologies compared by EROI [6]

Aesthetic considerations of wind power plants also have a significant role. Wind power plants are less likely to be perceived negatively in urbanized and industrial regions. Aesthetic issues are subjective and some people may find wind farms pleasant or see them as symbols of energy independence and local prosperity.

In some countries like Scotland studies predict wind farms will damage tourism, but in other countries some wind farms have become tourist attractions with organized sightseeing.

Like all mechanical systems, wind turbines produce some noise when they operate. Most of the turbine noise is masked by the sound of the wind itself, and the turbines run only when the

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wind blows. In recent years, engineers have made design changes to reduce the noise from wind turbines. Early model turbines are generally noisier than the most of new and larger models. As wind turbines have become more efficient, more of the wind is converted into rotational torque and less into acoustic noise.

Some people living close to wind power plants have complained about sound and vibration issues, but industry and government-sponsored studies in Canada and Australia showed that these issues do not adversely impact public health (Figure 7.).

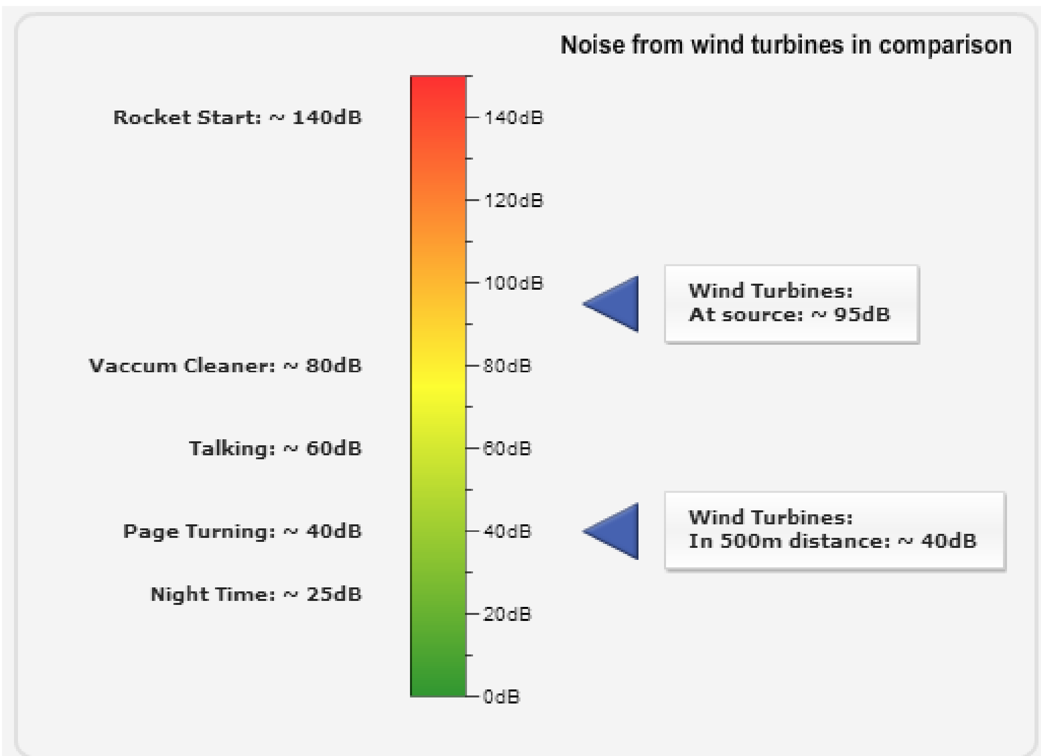

Figure 7: Noise comparison [7]

4.1 Technology data sheet – On-shore wind power plants

on shore application medium scale application (30 kW - 250 kW)			
Energy / Technical data			**Ref.**
Generating capacity for one turbine [kW]		30 – 250 kW	8,15
Rotor diameter [m]		8 m (30 kW)	8,10
Hub height [m]		35 m (100 – 400 kW)	8,10
Wind speed [m/s]	Minimum wind speed	2.5 m/s	10,16
	Rated power generation speed	9.5 m/s	10,16
	Maximum operation wind speed	25 m/s	10,16
Utilisation time [hours/year] or Average annual plant capacity factor			
Technical lifetime [years]		20 years	10,16
Construction time [years]		3 months	19
Environment data			
Noise [dB] at nearest neighbour, open land		60 dB at source (60 kW)	8
Financial data			
Specific investment, total costs [€/kW]		1500 - 3000 €/kWh	7
Operating and maintaining costs [€/kWh]		0.1 – 0.3 €/kWh	7

Cost structure			
Investment, capital costs			
	Share of total costs [%]		
Turbine, ex works	60 – 80		7
Foundation	5 – 20		7
Electric installation	2 – 5		7
Grid - connection	1 – 3		7
Land	n/a.		
Road construction	1 - 3		7
Consultancy	5 – 20		7
Financial costs	n/a.		

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4.2 Wind power plants bibliography

Legend:

Technical information on technologies ■ (yellow)

Economical information on technologies ■ (orange)

Environmental information on technologies ■ (green)

Legislative information on technologies ■ (red)

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5. Wave and tidal technology

Beside solar, wind and geothermal resources of energy the nature gives us one more free and large renewable resource, the ocean. The energy stored in the ocean comes in many shapes such as waves, tides, tidal currents, ocean currents, ocean thermal energy and energy from salinity gradients. Each energy source has different origins and requires different technologies for conversion. Utilization of wave and tidal energy technologies, as a potential commercial power sources are just beginning to reach viability.

Tidal energy is a form of hydro energy which can be converted into more useful forms of energy, such as electricity. Tides are the rise and fall of a sea level created by the gravitational pull of the Moon, to a lesser degree, the Sun and the rotation of the Earth. Some locations experience two nearly equal high and low tides, called a semi-diurnal tide; other shorelines experience only one high and one low tide, called a diurnal tide; and some places experience two uneven tides or one high and one low tide, which are called mixed tides (Figure 1.). As a result of the tides the tidal currents are generated.

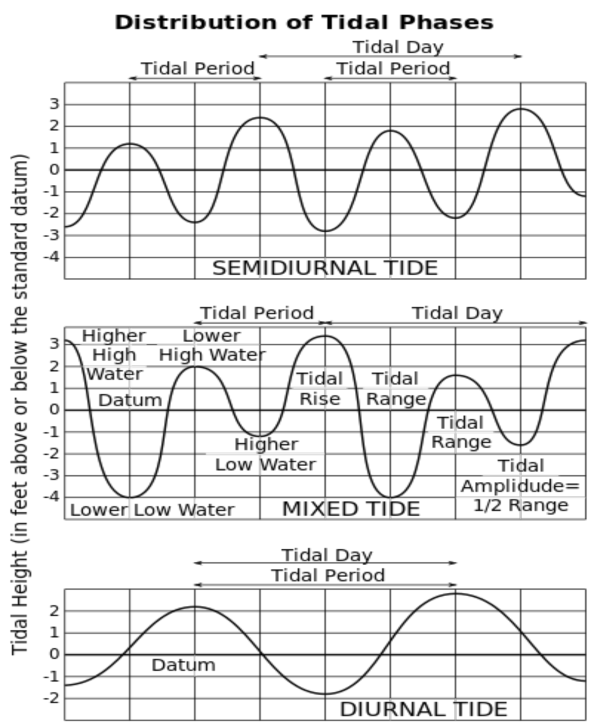

Figure 1: Types of tides [1]

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Tidal currents are horizontal movement of water caused by the difference in height of high and low tide. Tidal currents differ from ocean currents because they don't follow as continuous stream and they switch direction every time there is a transition between high and low tide. Though tides and tidal currents don't have much impact on the deep ocean, they can create rapid currents of up to 25 km/h when they flow in and out narrow areas like bays, estuaries and harbours.

Wave energy is also a form of hydro energy stored in the oceans, which can be captured and converted to do useful work (e.g. electricity generation, water desalination or the pumping of water into tanks). The wave is the surface motion of water caused by a wind. Waves can range in size from small ripples to waves over 30 m high. Figure 2 shows the dependence between the wave height and the wind speed for the year 1992. We can conclude that the greater wind velocity causes higher waves and this is especially the case in the Southern Hemisphere.

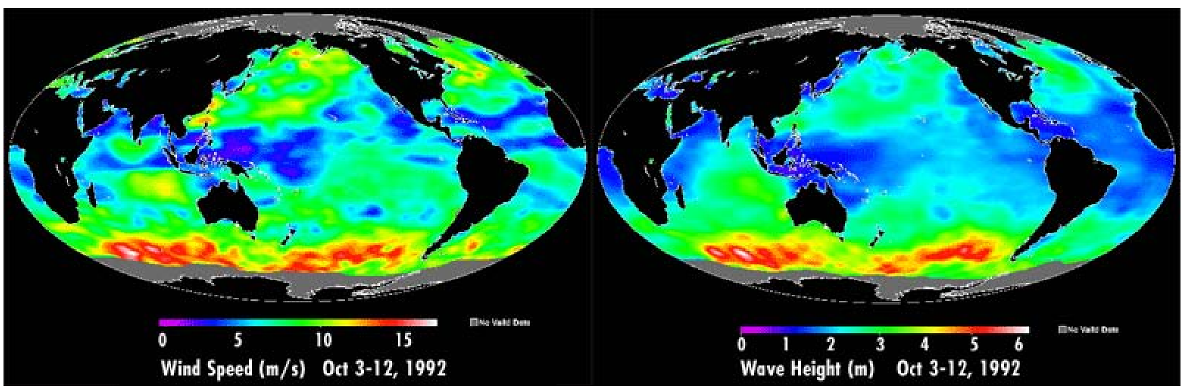

Figure 2: Global distribution of wind speed and wave height [2]

Ocean energy has the potential of providing the enormous amount of renewable energy to the world. Theoretical annual energy generation from tidal and wave energy is estimated around 800 TWh for tidal energy and from 8,000 to 80,000 TWh for wave energy. If this large amount of energy is to be captured the technology must be developed.

There are four methods for getting energy from the tides: tidal stream generator, tidal barrage, dynamic tidal power and tidal lagoon.

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Tidal stream generator, often referred to as a tidal energy converter is a device that uses the kinetic energy of moving water, in particular tides. Some types of these machines have similar design and function very much like underwater wind turbines and are often called tidal turbines. Tidal turbines draw kinetic energy from the tides on the same principle that wind turbines use to draw kinetic energy from the wind. Due to the higher density of water than the air (water is 784 times more dense than air), a single turbine can provide significant power even at low tide flow velocity compared with the same wind velocity. Considering that power depends on the density of a medium and cube of velocity, the speed of one-tenth of wind speed produces the same amount of energy for the same size of the turbines. There are several types of tidal stream generators such as horizontal axis turbines, vertical axis turbines, oscillating hydrofoils, Venturi devices, Archimedes screws and tidal kites (Figure 3.).

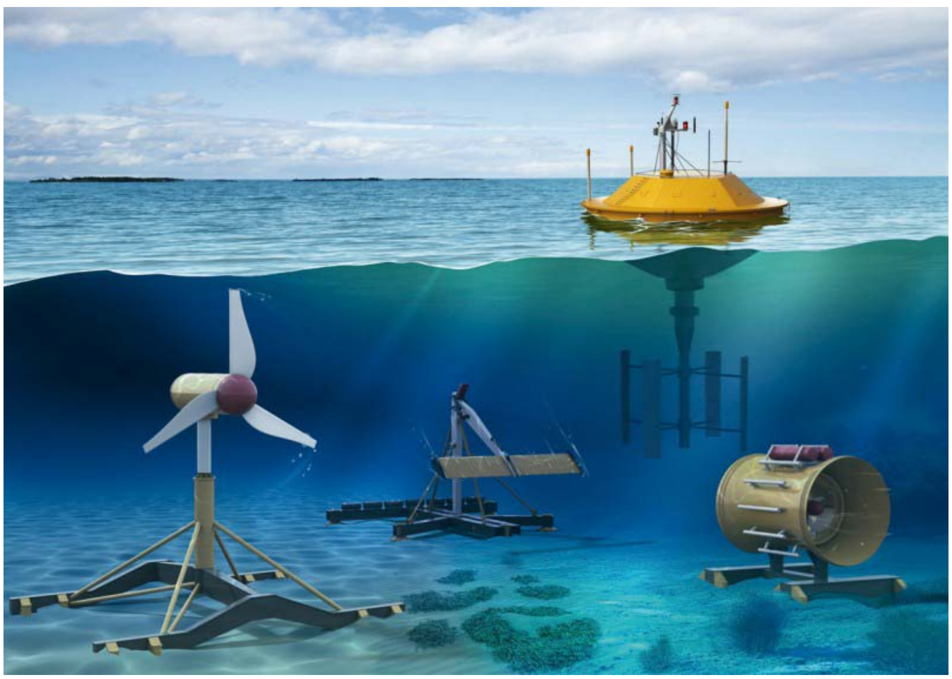

Figure 3: Tidal stream generator types [3]

Axial turbines are close in concept to traditional wind turbines only they operate under the sea surface. They have the highest number of prototypes that are currently operating. Some of the examples of different technologies are listed below.

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The AR-1000 is a 1 MW turbine developed by Atlantis Resources Corporation. The turbine was successfully deployed at the EMEC facility in Great Britain during the summer of 2011. The AR turbine series are developed for commercial use and deployment in open ocean. Their rated power is 1 MW at 2.65 m/s water flow velocity.

Verdant Power started a prototype project in New York, USA, back in 2007. It was the first major tidal power generation project. Strong currents posed a challenge for developers, the blades of the first prototype turbines broke and they were replaced with new reinforced turbines. The installed capacity was 175 kW.

The crossflow turbines were developed by Georges Darreius in 1923. These turbines can be deployed horizontally or vertically. The Gorlov turbine is a variant of the Darreius design with a helical design.

Oscillating devices do not have rotational parts. They use aerofoil sections instead, which are pushed sideways by flow. In 2003 a 150 kW oscillating hydroplane device called Stingray, was tested in Scotland. It uses hydrofoils to create oscillation, which then creates hydraulic power. Hydraulic motor, which is connected to a generator, is powered by hydraulic power.

A tidal kite is an underwater machine that converts tidal energy into electricity moving through a stream. Tidal kite is tethered by a cable to a fixed point. It floats through the current carrying a turbine. Due to its moving it has potential to generate 1000 times more energy than the stationary turbine. They are expected to work within flows as low as 1-2.5 m/s. Rated capacity will be between 150 – 800 kW. They can be deployed in waters from 50 to 300 m of depth. It is estimated that 1% of 2011's global energy demand could be provided by these devices.

Venturi devices operate on principle of the Venturi effect. Due to the pressure reduction speed must increase, according to Bernoulli's equation. Venturi devices use a shroud or duct in order to generate a pressure differential which is used to run a secondary hydraulic circuit which then generates power.

There are several mooring options that can be considered for fixing a tidal turbine to the sea floor (Figure 4.).

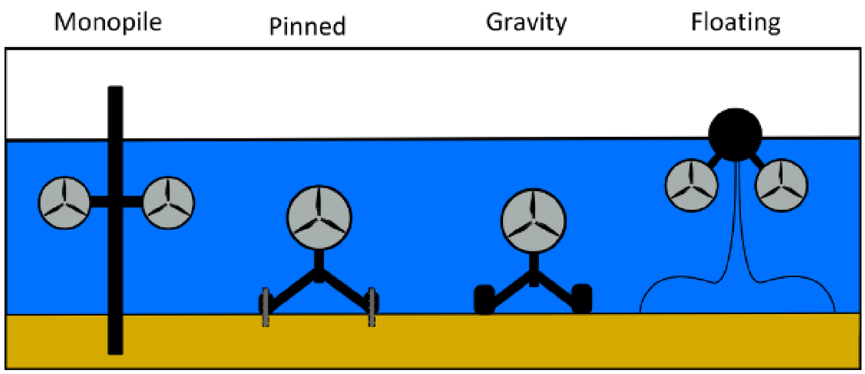

Figure 4: Different types of fixing a tidal turbine to the seabed [4]

"Monopile is a single tubular steel tower that can be drilled and grouted into a deep socket in the sea bed. Monopile foundations could be used for fully submerged devices as an alternative to gravity or pinned foundations.

Pinned foundation structures are drilled and grouted into the small sockets in the seabed. These foundations are suitable for turbines mounted close to the bottom of the water column.

Gravity Base will hold a tidal energy converter to the sea bed by means of a substantial mass, with the gravitational forces keeping the device fixed in place" [4].

"Floating buoyant turbine devices can be moored to the sea bed using either flexible or rigid moorings. There may also be an option of mounting multiple devices on one floating platform. Designs of this type can access the faster flowing currents located higher within the water column, but there may be some increased cyclic loading and fatigue stress caused by complex interactions due to the circular wave particle motion discussed" [4].

Tidal barrages make use of the potential energy in the difference between high and low tides (Figure 5.). The potential energy from a tide is seized through specialized dams. When the sea level rises and the tide begins to come in, the temporary increase in tidal power is channelled into a large basin behind the dam where it is holding a large amount of potential energy. With the receding tide, this energy is then converted into mechanical energy as the water is released through large turbines that create electrical power through generators. The barrage is usually built across a bay or river that is subject to tidal flow.

Only a few such plants exist. The first was the Rance Tidal Power Station, on the Rance River, in France, which has been operational since 1966 and generates 240 MW. A larger 254 MW plant began operation in Korea in 2011.

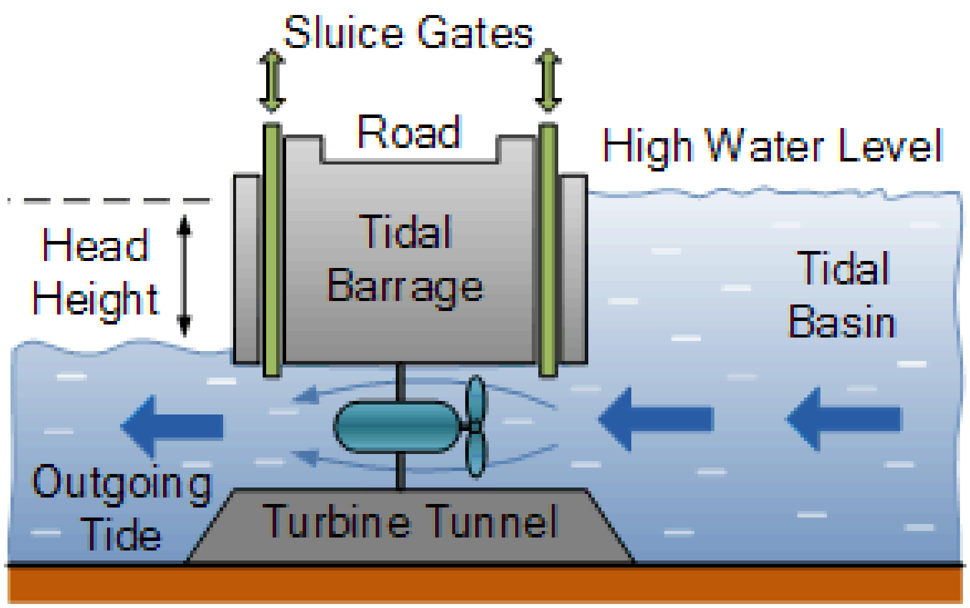

Figure 5: Scheme of tidal barrage [5]

Barrage systems are affected by the problems of high civil infrastructure costs associated with what is in effect a dam being placed across estuarine systems, and the environmental problems associated with changing a large ecosystem.

Dynamic tidal power (DTP) is an untried but promising technology that would exploit the interaction between potential and kinetic energies in tidal flows (Figure 6.). The concept was invented and patented in 1997 by Dutch coastal engineers Kees Hulsbergen and Rob Steijn. It proposes that very long dams can be built from coasts straight out into the sea or ocean without enclosing an area. Tidal differences are introduced across the dam, leading to a significant water-level differential in shallow coastal seas and strong coast-parallel oscillating tidal currents that can be found in the UK, China or Korea. It is estimated that some of the largest dams could accommodate over 15 GW of installed capacity. A DTP dam with 8 GW of installed capacity could generate about 21 TWh annually. The generation of tidal power is highly predictable due to the deterministic nature of tides and independent of weather conditions or climate change. Dynamic tidal power doesn't require a very high natural tidal range, but it requires an open coast where the tidal propagation is alongshore. Such tidal conditions can be found in many places around the world so the theoretical potential of DTP is very high.

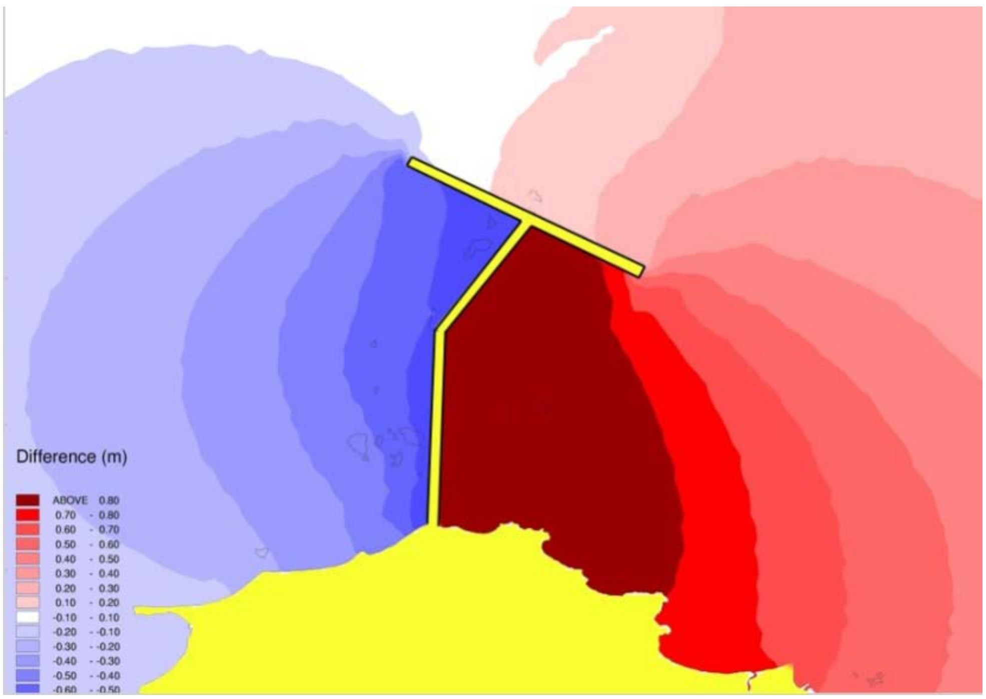

Figure 6: Dynamic tidal power [6]

Tidal lagoon is a newer tidal energy design option (Figure 7.). Circular retaining walls are embedded with turbines that can capture the potential energy of the tides. The created reservoirs are similar to those of tidal barrages, except that the location is artificial and does not contain a pre-existing ecosystem. The lagoons can also be in multiple formats without pumping. Geographically dispersed tidal lagoons with a time delay between peak productions would also flatten out peak production, providing near base load production, though at a higher cost than some other alternatives such as district heating renewable energy storage.

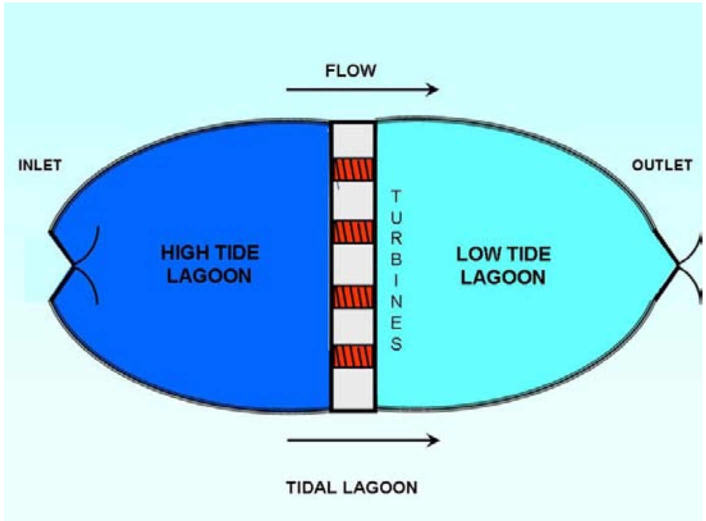

Figure 7: Tidal lagoon [7]

Environmental concerns of tidal power

Tidal power can have effects on marine life. The rotating turbine blades can accidentally kill swimming sea life. Some fish may no longer utilize the area if threatened with constantly rotating or noise-making objects. Marine life is a huge factor when placing tidal power energy generators in the water.

Tidal turbines - The main environmental concern with tidal energy is associated with a blade strike as high speed water increases the risk of organisms being pushed near or through these devices. Depending on the frequency and amplitude of sound generated by the tidal energy devices, this acoustic output can have varying effects on marine mammals.

Tidal barrage - Installing a barrage may change the shoreline within the bay or estuary, affecting a large ecosystem that depends on tidal flats. Migrating fish may also be unable to access breeding streams and may attempt to pass through the turbines.

Tidal lagoon - The main concerns are blade strike on fish attempting to enter the lagoon, acoustic output from turbines, and changes in sedimentation processes. However, all these effects are localized and do not affect the entire estuary or bay.

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Wave energy

Wind generated waves have the highest energy concentration among all different types of ocean waves. Wind waves are a result of the winds as they blow across the oceans. This energy is the natural storage of wind energy in the water near the free surface. Once created, wind waves can travel thousands of kilometres with little energy losses, unless they encounter head winds. Near the coastline the wave energy intensity decreases due to interaction with the seabed, but the energy dissipation near the shore can be compensated by natural phenomena as refraction or reflection. The strongest winds blow between 30˚and 60˚ in latitud e creating most of wave power in that area so the western coastlines at these latitudes experience the most powerful waves.

Ocean waves can be divided into two forms of energy. First is the kinetic energy of the water particles, which in general follow circular paths and the second is the potential energy of elevated water particles. On the average, the kinetic energy in a linear wave equals its potential energy. The energy flux in a wave is proportional to the square of the amplitude and to the period of the wave motion.

Wave energy conversion is being investigated in a number of countries, particularly in the member States of the European Union, Canada, China, India, Japan, Russia, the USA and others. In the last five years there has been an increasing interest in wave energy, especially in Europe. Recently wave energy companies have been highly involved in the development of new wave energy schemes such as the Pelamis, the Archimedes Wave Swing or the Wave Dragon.

Wave power devices are generally categorized by the method used to capture the energy of the waves, by location and by the power take-off system. Locations are shoreline, near shore and offshore.

Although over 1000 wave energy conversion techniques are patented worldwide, the apparent large number of concepts for wave energy converters can be classified within a few basic types:

- Oscillating Water Columns: Partially submerged, hollow structures open to the seabed below the water line. The heave motion of the sea surface alternatively pressurizes and

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depressurizes the air inside the structure generating a reciprocating flow through a turbine installed beneath the roof of the device.

- Overtopping devices: Devices that collect the water of incident waves in an elevated reservoir to drive one or more low head turbines. They can be floating or fixed to the shore.
- Heaving devices: They can provide a heave motion that is converted by mechanical and/or hydraulic systems in linear or rotational motion for driving electrical generators.
- Pitching devices: They consist of a number of floating bodies, hinged together across their beams. The relative motions between the floating bodies are used to pump high-pressured oil through hydraulic motors, which drive electrical generators.
- Surging devices: They exploit the horizontal particle velocity in a wave to drive a deflector or to generate pumping effect of a flexible bag facing the wave front.

Advantages and disadvantages of usage of wave power are listed below.

Advantages:

- Wave power converters produce power without the use of fossil fuels.
- The power plants are located in the ocean without much visual intrusion.
- Wave power is a more predictable compared to wind-
- Extracting energy from waves can help costal protection, because the wave heights are reduced.

Disadvantages:

- The initial prototype development at sea is expensive.
- Wave power converters take up large amounts of space and they much depend on the type of converter and how much power is extracted.

5.1 Technology data sheet – Tidal energy

tidal – potential tidal – kinetic, medium scale application (< 1 MW)			
Energy / Technical data			Ref
Generating capacity for one turbine [kW]		25 kW - 1 MW	8,11,14
Rotor diameter [m]		5 - 35 m	14,16
Minimum speed [m/s]/height [m]		0.4 - 1.5 m/s / 6 - 36 m	14,15
Utilisation time [hours/year] or Average annual plant capacity factor		n/a	9
Technical lifetime [years]		10 - 20	8
Construction time [years]		1 - 3	8,12
Financial data			
Specific investment, total costs [€/kW]		5 300 - 9 500 €/kW	8,12,17
Operating and maintaining costs [€/kW/year]		115 - 150 €/kW/year	8
Cost structure			
Investment, capital costs			
	Share of total costs [%]		
Turbine, ex works	10 - 35		12,13
Foundation	10 - 15		12,13
Electric installation	20 - 35		12,13
Grid - connection	5 - 15		12,13

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5.2 Technology data sheet – Wave energy

wave medium scale application (< 1 MW)			
Energy / Technical data			Ref
Generating capacity for one turbine [kW]		5 - 800 kW	8,11,14
Rotor diameter [m]		n/a	
Minimum speed [m/s]/height [m]		n/a	
Utilisation time [hours/year] or Average annual plant capacity factor		1500 - 4000 kWh/kW	9,13
Technical lifetime [years]		10 - 25	7,8,10
Construction time [years]		3 - 4	7,8,10
Financial data			
Specific investment, total costs [€/kW]		5 000 - 11 000 €/kW	7,8,11
Operating and maintaining costs [€/kWh]		0.02 €/kWh	7,8,10
Cost structure			
Investment, capital costs			
	Share of total costs [%]		
Turbine, ex works	20 - 60		7,13
Foundation	5 - 10		7,13
Electric installation	5 - 20		7,13
Grid - connection	5 - 10		7,13

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5.3 Wave and Tidal bibliography

Legend:

Technical information on technologies

Economical information on technologies

Environmental information on technologies

Legislative information on technologies

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Conclusion

The objective of this technical, economical and environmental analysis of low and medium size blue energy technologies is to provide overview of techno-economical and environmental data from existing installation in Adriatic-Ionian region and EU, taking into account that these data could be helpful for future analysis of pilot plants on blue energy in Adriatic-Ionian region as well as on European level.

Questionnaire for four technologies has been prepared by partner in charge of the action and was given to ENERCOAST partners to fill in. Partners have focused only on one technology and all technical, economical and environmental data as well as technology bibliography were collected for partner technology. Despite the lack of comparative data on each technology from ENERCOAST partner countries, the results from this analysis could be useful as a basis for a preparation of new case studies on blue energy technologies. The importance of this report was already showed in preparation of the case studies under **Action 3: "*Case studies*"** of ENERCOAST project in which technical and economical data presented in this report have been used.

According to our findings there is a lack of data for small and medium size installation of blue energy technologies in Adriatic-Ionian region. Furthermore, the blue energy technologies analysed in this report have very low penetration level which can be explained by the high investment costs and maturity of analysed blue energy technology. Analysis conducted under Action 3 shows that potential for these technologies exist and some of these technologies such as sea water heat pumps and wind turbine can be profitable without any additional subsidies.

Taking into account future role of the blue energy technologies in ENERCOAST project partner countries, analysed in the Action 1, we can expect that penetration level of these technologies will increase. In the case of cooling and heating focus will be on sea water heat pumps and solar cooling technologies while in the case of electricity production wind energy will have main role. The ocean energy at the moment has very love penetration level mainly because of a high investment costs which are very technology specific. Up to now, the ocean energy projects are mainly financed through small size research projects and very little through big private projects.

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In the case of environmental concerns of blue energy technologies, analysis shows that wave and tidal projects have highest impact on environment. The main environmental concern with tidal energy is associated with a blade strike as high speed water increases the risk of organisms being pushed near or through these devices. Because of this marine life is a very important factor when placing tidal power energy generators in the water. In the case of wind energy main environmental concern is noise which is produced by turbines when it operated but, in recent years the noise level is reduced due to constant research in this field. In the case of sea water heat pumps and solar cooling technologies main environmental concern is associated with refrigerant used in these technologies but constant research on these technologies is leading to increase of the safety and to using more environmental user friendly gases.

Taking into account sea water and solar energy potential of Adriatic-Ionian region, ENERCOAST project propose to the MED Programme to consider higher involvement in the financing of project related to blue energy technologies such as: Solar cooling and sea water heat pumps which are considered as a most promising solution for lowering CO_2 emissions and growing energy need. The role of heat pumps and solar technologies as well as wind and ocean energy in the realisation of ambitious goal of European Union on energy system which is entirely based on renewable energy sources is very important and showed in ***RE-Thinking 2050*** report for EU.

ANNEX I: Questionnaire on Technical, economical and Environmental advantages and disadvantages of analysed technology/Installation

PROJECT ENERCOAST

Questionnaire on Technical, Economical and Environmental advantages and disadvantages of sea water heat pumps (low-medium power)

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define the type and size	☐ heating ☐ cooling	☐ micro scale application (< 25 kW) ☐ small scale application (< 100 kW) ☐ medium scale application (< 250 kW)
Manufacturer data		
Company name and location		
Company contact and website		
Product info		
Short description of product with some information about installed capacities and possible location for installation as well as future costs		
Technology/installation photos and diagrams		
Photos/diagrams of application		

Energy / Technical data	
Heating capacity per unit [kW heat]	
Cooling capacity per unit [kW cooling]	
Coefficient of performance	
Operating temperature +-°C	
Utilisation time [hours/year] or Average annual plant capacity factor	
Technical lifetime [years]	
Construction time [years]	
Environment	
Refrigerants	
Financial data	
Specific investment, total costs [€/kW heat out]	
Operating and maintaining costs [€/kW heat out]	
Cost structure	

Investment, capital costs			
	Share of total costs [%]		
Heat pump			
Pipe connection			
Other costs			

SWOT Analysis of technology/installation	
Strengths	**Weaknesses**
•	•
Opportunities	**Threats**
•	•

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Questionnaire on Technical, Economical and Environmental advantages and disadvantages of solar cooling technologies (low-medium power)

define the type and size	☐ absorption solar cooling ☐ adsorption solar cooling ☐ PV cooling	☐ micro scale application (< 20 kW) ☐ small scale application (< 70 kW) ☐ medium scale application (< 250 kW)

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Manufacturer data	
Company name and location	
Company contact and website	
Product info	
Short description of product with some information about installed capacities and possible location for installation as well as future costs	
Technology/installation picture	
Photos/diagrams of application	

Energy / Technical data				
Cooling capacity			kW	
Heating capacity			kW	
Chilled-hot	Temperature	Inlet	°C	

water	(cooling)	Outlet	°C	
	Temperature (heating)	Inlet	°C	
		Outlet	°C	
	Maximum operating pressure		kPa	
Cooling water	Temperature	Inlet	°C	
		Outlet	°C	
	Maximum operating pressure		kPa	
	Heat rejection		kW	
Heat medium	Heat input		kW	
	Temperature	Inlet	°C	
		Outlet	°C	
		Range	°C	
	Flow rate		l/s	
Electricity	Consumption		W	

Environment data	
Noise [db] level	

Financial data				
Specific investment, total costs [€/kW]				
Operating and maintaining costs [€/kWh]				
Cost structure				
Investment, capital costs			**O&M costs**	
	Share of total costs [%]	**Share of other costs [%]**		
Cooling units, ex works			Regular service	
Foundation			Repair and spear parts	
Electric installation			Power from the grid	
Piping and storage			Administration	
Solar collectors			Miscellaneous	
Design				

SWOT Analysis of technology/installation	
Strengths	**Weaknesses**

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•	•
Opportunities	**Threats**
•	•

PROJECT ENERCOAST

Questionnaire on Technical, Economical and Environmental advantages and disadvantages of tidal technologies (low-medium power)

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define the type and size	☐ wave ☐ tidal - potential ☐ tidal - kinetic	☐ micro scale application (< 250 kW) ☐ small scale application (< 500 kW) ☐ medium scale application (< 1 MW)
Manufacturer data		
Company name and location		
Company contact and website		
Product info		
Short description of product with some information about installed capacities and possible location for installation as well as future costs		
Technology/installation picture		
Photos/diagrams of application		

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Energy / Technical data				
Generating capacity for one turbine [kW]				
Rotor diameter [m]				
Minimum speed [m/s]/height [m]				
Utilisation time [hours/year] or Average annual plant capacity factor				
Technical lifetime [years]				
Construction time [years]				
Financial data				
Specific investment, total costs [€/kW]				
Operating and maintaining costs [€/kWh]				
Cost structure				
Investment, capital costs			**O&M costs**	
	Share of total costs [%]	**Share of other costs [%]**		
Turbine, ex works			Land rent	
Foundation			Insurance	
Electric installation			Regular service	
Grid - connection			Repair and spear parts	

SWOT Analysis of technology/installation	
Strengths	**Weaknesses**
•	•
Opportunities	**Threats**
•	•

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PROJECT ENERCOAST

Questionnaire on Technical, Economical and Environmental advantages and disadvantages of wind energy technologies (low-medium power)

define the type and size	☐ on shore application ☐ off shore application	☐ micro scale application (< 5 kW) ☐ small scale application (5 kW - 30 kW) ☐ medium scale application (30 kW - 250 kW)
Manufacturer data		
Company name and location		
Company contact and website		
Product info		
Short description of product with some information about installed capacities and possible location for installation as well as future costs		
Technology/installation picture		
Photos/diagrams of application		

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Energy / Technical data		
Generating capacity for one turbine [kW]		
Rotor diameter [m]		
Hub height [m]		
Wind speed [m/s]	Minimum wind speed	
	Rated power generation speed	
	Maximum operation wind speed	
Utilisation time [hours/year] or Average annual plant capacity factor		
Technical lifetime [years]		
Construction time [years]		
Environment data		
Noise [db] at nearest neighbour, open land		
Financial data		
Specific investment, total costs [€/kW]		
Operating and maintaining costs [€/kWh]		

Cost structure				
Investment, capital costs			**O&M costs**	
	Share of total costs [%]	**Share of other costs [%]**		
Turbine, ex works			Land rent	
Foundation			Insurance	
Electric installation			Regular service	
Grid - connection			Repair and spear parts	
Land			Power from the grid	
Road construction			Administration	
Consultancy			Miscellaneous	
Financial costs				

SWOT Analysis of technology/installation	
Strengths	**Weaknesses**
•	•
Opportunities	**Threats**
•	•

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ANNEX II: Bibliography template for technology

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		Document covering following field																											
		Technical information on technologies							Economical information on technologies							Environmental information on technologies							Legislative information on technologies						
Document full name	document link	Wind turbine		Heat pumps with sea water	Solar cooling		Tidal current technologies		Wind turbine		Heat pumps with sea water	Solar cooling		Tidal current technologies		Wind turbine		Heat pumps with sea water	Solar cooling		Tidal current technologies		Wind turbine		Heat pumps with sea water	Solar cooling		Tidal current technologies	
		onshore	off-shore		PV module	Colectors	Wave	Tidal	onshore	off-shore		PV module	Colectors	Wave	Tidal	onshore	off-shore		PV module	Colectors	Wave	Tidal	onshore	off-shore		PV module	Colectors	Wave	Tidal
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