



# FLORES

Offshore Renewable Energies  
partnership in the Pact for Skills

## Educational Materials for the Offshore Renewable Energies

Secondary School Guidebook

**Lesson 4:** Wave energy

# 5



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## About this guidebook

**Forward Looking at the Offshore Renewables** (FLORES) will promote the core activity of the Large-scale partnership launching the Pact for Skills in the Offshore Renewable Energies (ORE) sector. FLORES will support the most committed stakeholders in the ORE, underpinning the success of the offshore renewable energy strategy with the stimulation of dedicated training offers. The partnership will promote the skilling process for the new jobs expected in the sector, estimated to account for between 20,000 and 54,000 new workers in the following five years and contribute to improve upskilling opportunities in the field of the actual ORE workforce.

FLORES prepared a set of educational materials for secondary school teacher presenting six topics:

- 1) introduction to offshore renewables;
- 2) wind energy;
- 3) solar energy;
- 4) ocean currents energy;
- 5) wave energy;
- 6) tidal energy.

For every lesson there is a guidebook and additional sources as well as a PowerPoint presentation aimed at developing practical Science, Technology, Engineering and Mathematics (STEM) experiences for secondary school students.

The objective of these educational materials is to empower teachers to introduce offshore renewable energy as a new topic and seamlessly integrate ocean literacy into their lessons. It is a «teach the teacher» resource that equips educators with the methodology required to independently craft lesson plans, while also providing them with a curated selection of existing resources.

This guidebook is aimed at students in secondary school, and the content can be adapted to younger and older students ranging from 12-18.

Project duration: January 2023 – December 2024 (24 months)

[www.oreskills.eu](http://www.oreskills.eu)

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# Guidebook



## Offshore renewable energies: wave energy

This document is intended for secondary school teachers and serves as a guide for lessons introducing wave energy as an energy source.



**Duration:** approx. 45 minutes

*Lesson time can be extended with the use of additional materials provided under the scenario.*



**Target group:** secondary school pupils



**Learning objectives:**

- ▶ To familiarize pupils with the definition of wave energy.
- ▶ To explain how waves are created and how energy can be generated from it.
- ▶ To inform about the potential and status of wave energy.
- ▶ To understand what are the wave energy generation technologies.
- ▶ To learn about the advantages and disadvantages of using this type of energy.

### Competencies and skills to be developed:

- ▶ Ability to define wave energy.
- ▶ Ability to identify and compare technological solutions.
- ▶ Ability to present the advantages and disadvantages of wave energy.
- ▶ Ability to transform information about wave energy into logical and understandable conclusions.
- ▶ Ability to express opinions on the determinants of development of wave energy.

### Proposals for evaluating learning outcomes (elective):

- ▶ Evaluation of students through their activity in discussion and participation in group tasks.
- ▶ Debates between two groups of students, one advocating for wave energy while the other advocates for ocean currents.
- ▶ A short quiz to test students' understanding of wave energy.

### Including diversity and inclusive aspects in teaching:

- ▶ During the lesson, the teacher should pay attention to the different perspectives and approaches of the students towards wave energy.
- ▶ Encourage open discussion and respect for different points of view.
- ▶ Enable students to conduct their own research and experiments to explore a topic according to their individual interests.
- ▶ Show sensitivity to the needs of students with different religious beliefs, gender, disabilities, and background ensuring that they have equal opportunities to be included in the learning process.
- ▶ Recognize that your classroom may include students whose parents/family/close relatives/family friends work in the fossil fuels industry. It's vital to create a safe and inclusive space where they can freely learn, ask questions, and share their perspectives on renewable energies, fostering a richer and more holistic dialogue for all.

**Lesson scenario:****Offshore renewable energies – wave energy****Lesson objectives:**

- ▶ To familiarize students with the definition and functioning of different wave energy technology solutions.
- ▶ To introduce wave energy as a renewable energy source, along with its advantages and disadvantages.
- ▶ To understand the status and key determinants of wave energy development.

**Working methods:**

- ▶ Lecture
- ▶ Discussion
- ▶ Power Point presentation
- ▶ Brainstorming

**Work format:**

- ▶ Group work

**Teaching tools:**

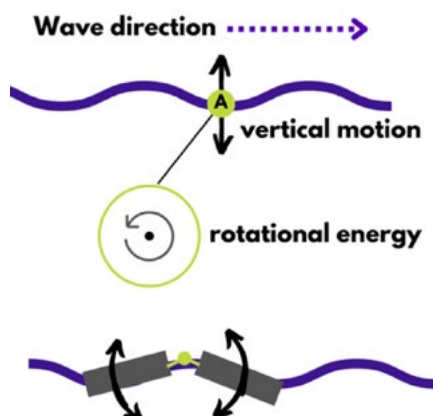
- ▶ Multimedia projector
- ▶ Multimedia presentation
- ▶ Film
- ▶ Computer with Internet access

**Course of the lesson:****I. Introduction (5 minutes)**

- 1 Welcoming students and introducing the topic of the lesson.

**II. Lecture with multimedia presentation (35 minutes)**

- 1 As the wave moves in, the point A will go up and down pushing the wheel to rotate. Therefore, vertical movement will produce a rotational movement and rotational movement is what we need to generate electricity.



- ▶ Two objects floating in the water connected through a coupling. As the wave goes up and down, the objects will go up and down also. This means that the coupling is going to flex in and by putting a ratchet device on it, it will act in the same way to rotate and eventually produce electricity.
- ▶ The teacher presents the potential of wave energy in the world and explains, based on the wave power map, which areas are the most suitable for development.

- 2 The teacher presents the status of wave energy projects.
- 3 The teacher shows and explains the technology that is used to harness wave power.
- 4 The teacher presents the advantages and disadvantages of wave energy production.
- 5 The teacher moderates the discussion on the future of this technology and to wrap up asks pupils what take-aways they have from the lesson.

### III. Summary and conclusion (5 minutes)

- 1 Encourage students to explore the topic and seek other information on the subject.
- 2 Thank students for participating in the lesson

## Introduction

The history of wave power research spans more than two hundred years. The Frenchman Pierre-Simon Girard is recognized as the first holder of a wave power patent in 1799<sup>1</sup>.

The first ever commercial wave energy system was installed in Scotland's Islay in 2000. The Islay LIMPET (Land Installed Marine Power Energy Transmitter) was a 500 kW wave energy collector connected to the National Grid. The plant was decommissioned in 2012 and today only the concrete building remains on the shoreline<sup>2</sup>.

## Comments on the slides

### Slide 3 - Waves transmit energy, not water

A sea wave is energy passing through the sea. Energy is transferred in different ways through waves. For example, vibrations and magnetic fields in electromagnetic waves or vibrations of particles in sound. In water waves, the energy is transferred through vibration of water particles.

Winds blow over oceans, transferring their energy to the water and causing the particles to move in a circular motion. The rise and fall of water molecules create a wave, that moves in the direction of the wind. While it appears that waves move in a forward direction across the surface of the water, the sea water stays almost in the same place passing its energy along the line. A good comparative illustration is a crowd of people doing a Mexican wave in a stadium: they stay in the same location, but the wave they create travels around the arena.

#### Causes of wave formation<sup>3</sup>:

- ▶ Wind (friction of the wind against the surface of the water)
- ▶ Baric (change in atmospheric pressure causes long waves and changing water levels)
- ▶ Tidal (the effect of the attraction of the moon and sun, a specific type of wave)
- ▶ Seismic (caused by earthquakes)
- ▶ Ships (caused by the movement of solid bodies).

### Slide 4 - Kinetic and potential energy of wave to generate electricity

As waves roll through the ocean, they create kinetic energy, or movement. This movement can be used to power turbines, which, in turn, create energy that can be converted into electricity.

Wave energy converters are devices that harvest the energy contained in ocean waves and use it to generate electricity. When winds blow over the ocean they transmit some of their kinetic energy to the ocean's surface creating wave energy. This form of energy contains both kinetic energy of the water particles that generally follow circular paths (the radius of which decreases with depth) and potential energy of elevated water particles<sup>4</sup>.

A wave energy converter device converts the kinetic or potential energy contained in sea waves to usable energy, mainly in the form of electricity.

1 Offshore wave power measurements—A review.

<https://www.sciencedirect.com/science/article/pii/S1364032111003704>

2 Sea Wave Energy. A Review of the Current Technologies and Perspectives.

<https://www.mdpi.com/6604/20/14/1073-1996>

3 Wave mechanism of sea waters. Criteria division and types of wave action of seas and oceans, Integrated Educational Platform, <https://zpe.gov.pl/>

4 George Lemonis, Wave and Tidal Energy Conversion. Encyclopedia of Energy, 2004.

<https://www.sciencedirect.com/science/article/abs/pii/B012176480X003442>



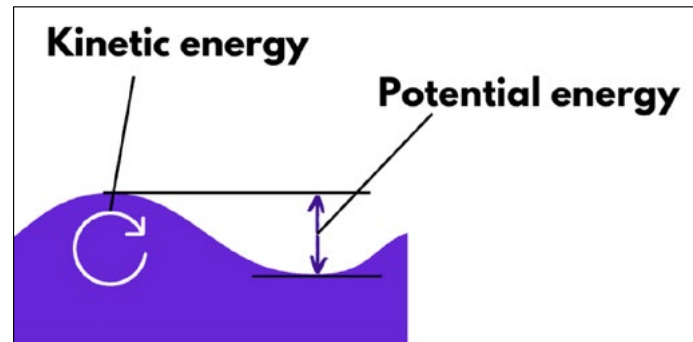


Figure 1. Wave energy components.

Video to explore the topic: <https://www.youtube.com/watch?v=FxdbD-N7pHE>

### Slide 5 - Wave energy potential could meet all global energy demand

Wave energy resources are more spatially distributed than tidal resources, which can be seen in the huge potential of wave energy. The global theoretical potential of wave energy is 29 500 TWh per year, which means that wave energy alone could meet all global energy demand (Mørk et al., 2010). Although varying seasonally and in the short term, waves can be forecast reliably and are widely considered to be a reliable energy source. The global distribution of wave power levels is presented in the Figure below, which shows that mid-latitude regions have lower resource levels and that the latitudes between 30 and 60 degrees deliver more powerful waves, particularly in the southern hemisphere.<sup>5</sup>

Especially large resources are located along the western European coast, off the coasts of Canada and the United States, and along the southern coasts of Australia and South America.<sup>6</sup>

### Slide 6

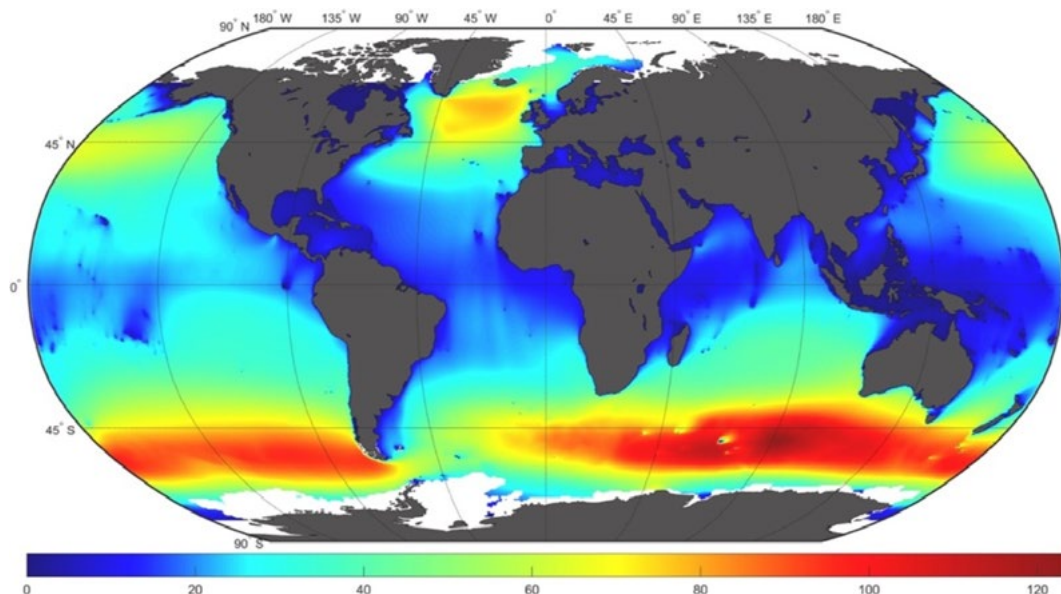


Figure 2. Global mean value of wave power,  $P$  (kWm).

<sup>5</sup> IRENA (2020), Innovation outlook: Ocean energy technologies, International Renewable Energy Agency, Abu Dhabi.

<sup>6</sup> George Lemonis, Wave and Tidal Energy Conversion. Encyclopedia of Energy, 2004.  
<https://www.sciencedirect.com/science/article/abs/pii/B012176480X003442>



## Slide 7 - 24.9 MW of installed capacity globally in 2022

In 2022, the global cumulative installed capacity for wave energy reached 24.9 MW globally of which 12.7 MW was in European sea basins. 400 kW is still currently in the water with 12.3 MW having been decommissioned following the completion of testing and demonstration programmes.<sup>7</sup>

The technology readiness level of wave energy is lower than that of tidal energy, and its deployment is currently restricted to demonstration and pilot projects. Therefore, there are currently 33 wave energy converters around the globe with a total capacity of 2.3 MW, deployed in 9 projects across 8 countries and 3 continents. These are located in the waters off Hawaii, France, Gibraltar, Israel, Italy, Portugal and Spain.<sup>8</sup>



Figure 3. Global distribution of wave energy projects.

## Slide 8 - Technology to harness the wave power

Over the years three main working principles to harness energy from waves have emerged<sup>9</sup>:

- ▶ oscillating water columns (OWC) which compress air to drive an air turbine
- ▶ overtopping devices (OD) which use the potential energy of water that spills into a closed reservoir to subsequently drive a hydraulic turbine
- ▶ oscillating bodies (OB) converters which use different conceptualizations to transform wave motion between bodies (up/down, forwards/backwards, side to side) into electricity.

Wave energy technologies have not experienced a convergence towards one type of design, as has happened for other technologies such as wind energy. Many different technologies are being pursued, some of which are presented in the Figure below.

<sup>7</sup> Ocean Energy Europe (2023), Ocean Energy. Key trends and statistics.

<sup>8</sup> IRENA (2020), Innovation outlook: Ocean energy technologies, International Renewable Energy Agency, Abu Dhabi.

<sup>9</sup> IRENA (2020), Innovation outlook: Ocean energy technologies, International Renewable Energy Agency, Abu Dhabi.

In recent years, despite the absence of a clear technology convergence for wave technologies, many deployments are of the “point absorber” type. Energy is generated from the movement of a buoy caused by waves coming from all directions, relative to the base connection.<sup>10</sup>

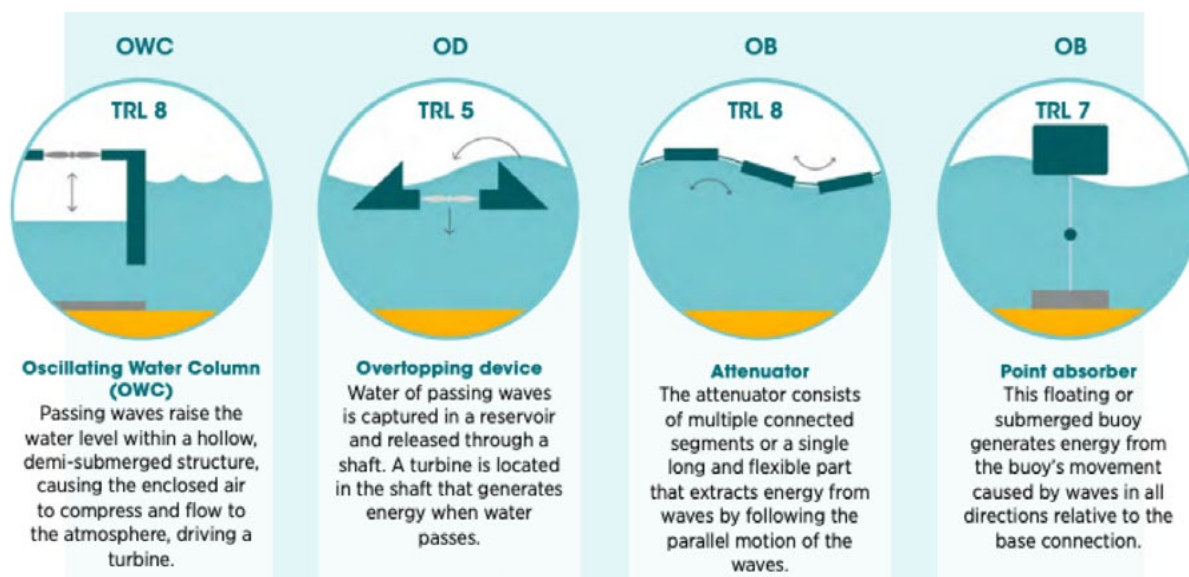


Figure 4. Different wave energy technologies

Technology Readiness Levels (TRL) are a type of measurement system used to assess the maturity level of a particular technology. TRL is a scale from 1 to 9 where 1-3 represent the research phase, 4-5 the development phase, 6 the demonstration phase and 7-9 the deployment phase (with 7 representing prototype demonstration and 9 a fully deployed, proven and operational technology).

<sup>10</sup> IRENA (2020), *Fostering a blue economy: Offshore renewable energy*, International Renewable Energy Agency, Abu Dhabi.

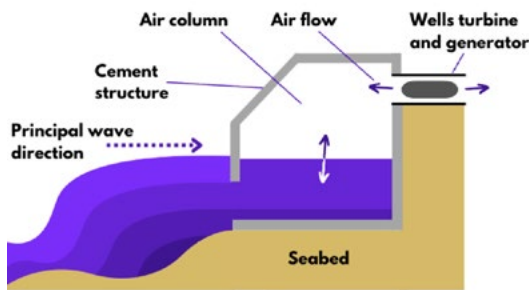


Figure 5. Oscillating Water Column

### More to investigate on wave energy technology

Oscillating Water Column (OWC) system consists of a partially submerged chamber, or a structure located near the shoreline. The chamber is open to the ocean and has an air turbine or a wells turbine installed inside it.

The primary components of OWC system are:

- ▶ Chamber – main structure of OWC. The chamber is open at the bottom and submerged in water allowing waves to enter and exit.
- ▶ Air turbine/ wells turbine – the turbine is connected to a generator that converts the mechanical energy of the rotating turbine into electrical energy.

The working principle is as follows:

- 1 As ocean waves approach the shoreline, they enter the chamber through the opening at the bottom. The waves cause the water level inside the chamber to rise and fall.
- 2 When the water level rises the air inside the chamber is compressed forcing it to flow out through the air turbine. As the water level falls the air is drawn back into the chamber creating the reverse airflow. This oscillating airflow is the key to OWC system operation.
- 3 The oscillating airflow drives the turbine blades causing them to rotate.
- 4 The rotating turbine is connected to a generator which converts the mechanical energy of turbine into electrical energy.

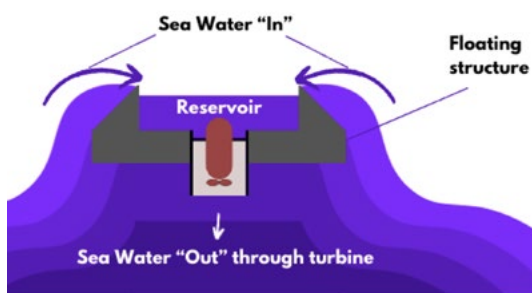


Figure 6. Overtopping Devices

Overtopping systems utilize the kinetic energy of waves to generate electricity through a barrier or a reservoir. The system works by allowing waves to break over a barrier which causes water to flow into a reservoir. The water in the reservoir then flows through a turbine which generates electricity.

Surface attenuators generally have multiple segments connected to one another and that are oriented parallel with incoming waves. They use the rise and fall of swells to create a flexing motion that may be converted into rotation or drive hydraulic pumps to generate electricity.

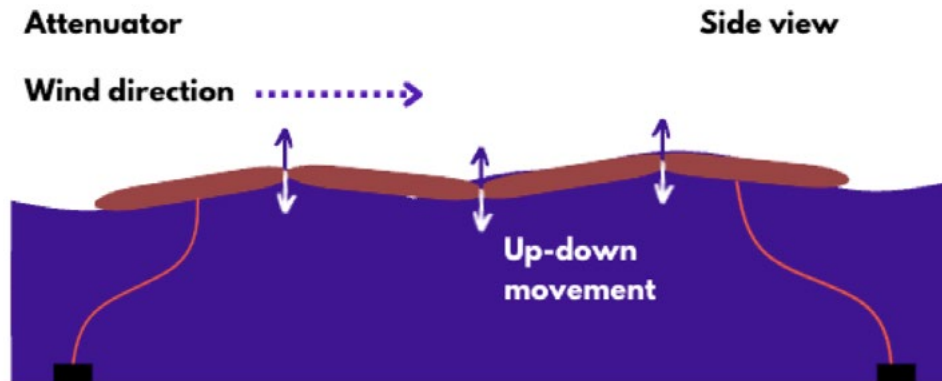


Figure 7. Attenuator

### Slide 9 - Advantages of wave energy

#### What are the main advantages of wave energy?<sup>11</sup>

- ▶ **Renewable:** waves are driven by wind, which move solar energy around the Earth. As long as the Sun is a part of our solar system, wave energy will be a renewable source of power.
- ▶ **Reliable:** waves are always in motion. They aren't dependent on the season or the weather.
- ▶ **Accessible:** approximately 72% of the Earth is covered by water – and 2.4 billion people live within 100 kilometres of the coastline. Wave energy has the potential to become an important energy resource for billions of people worldwide.
- ▶ **High-energy:** it's estimated that harnessing the movement of the oceans could produce up to 29 500 TWh per year (terawatt hours) of electricity – the world's electricity consumption (in 2022 – 25 350 kWh<sup>12</sup>)
- ▶ **Clean:** wave energy produces no greenhouse gases or harmful pollutants.
- ▶ **Economic advantages:** utilising wave energy can provide jobs for millions worldwide and reduces the need for imported fossil fuels.
- ▶ **No land damage:** generating energy from waves has no impact on terrestrial ecosystems.

<sup>11</sup> <https://www.studysmarter.co.uk/explanations/environmental-science/energy-resources/wave-energy/>

<sup>12</sup> <https://www.statista.com/statistics/280704/world-power-consumption/>

**Slide 10 - What is the catch with wave energy? Why don't we have more of it?****The main drawbacks of wave energy are following <sup>13</sup>:**

- ▶ **Visually unappealing:** wave energy technology could be considered an eyesore, and may impact tourism in coastal areas, causing a knock-on effect on the local economy.
- ▶ **Damage to marine life:** because wave energy technology is relatively new, scientists cannot be sure of the impacts on marine life. Concerns include disturbance to the sea floor, damage to benthic habitats (affecting animals such as crabs and starfish), noise pollution, and a danger of toxic chemical leaks into the water.
- ▶ **Ship disturbance:** wave technology may impact the passage of ships and other vessels.
- ▶ **Initial cost:** most wave technology is still in the early stages of development, so it's expensive to build and install. However, it's expected that construction costs will fall as wave technology becomes more common.
- ▶ **Maintenance:** inspecting and repairing wave energy technology is difficult, time-consuming, and expensive. Fun fact: Such work can be conducted in three manners: one possibility is to use divers, a second is to use underwater robots, and the third combines both divers and ROVs.<sup>14</sup>

Noise pollution, unwanted or excessive sound that can have deleterious effects on human health, wildlife, and environmental quality.

**Main take-aways:**

- ▶ **Renewable resource:** Wave energy is a renewable resource because it relies on the natural motion of ocean waves, which are driven by wind patterns and tides. It will not deplete as long as the Earth's oceans exist.
- ▶ **Clean energy source:** Wave energy is considered a clean and environmentally friendly energy source because it produces no greenhouse gas emissions or air pollutants.
- ▶ **Consistent and predictable:** Unlike some other renewable energy sources like solar and wind, ocean waves are relatively consistent and predictable, making wave energy a reliable source of power.
- ▶ **Geographic variability:** Wave energy potential varies by location. Mid-latitude regions have lower resource levels and the latitudes between 30 and 60 degrees deliver more powerful waves, particularly in the southern hemisphere.
- ▶ **Energy conversion technologies:** Several technologies are used to capture wave energy, including oscillating water columns, oscillating bodies and overtopping devices.
- ▶ **Environmental impact:** The installation of wave energy devices can have environmental impacts, including potential disruption to marine ecosystems and navigation. It is crucial to assess and mitigate these impacts during the planning and deployment phases.
- ▶ **Research and development:** Wave energy is still in the early stages of development, and ongoing research is focused on improving the efficiency of energy capture devices, reducing costs, and increasing the commercial viability of wave energy as a renewable energy source.

<sup>13</sup> <https://www.studysmarter.co.uk/explanations/environmental-science/energy-resources/wave-energy/>

<sup>14</sup> Deployment and Maintenance of Wave Energy Converters at the Lysekil Research Site: A Comparative Study on the Use of Divers and Remotely-Operated Vehicles. <https://www.mdpi.com/39/2/6/1312-2077>

**QUIZ: Ocean currents energy**

**Guidelines:** Adapt the quiz to your needs. You can use available apps, such as Kahoot, to create an online version or print and hand out to pupils.

**Task 1: Mark whether the given sentence is true or false**

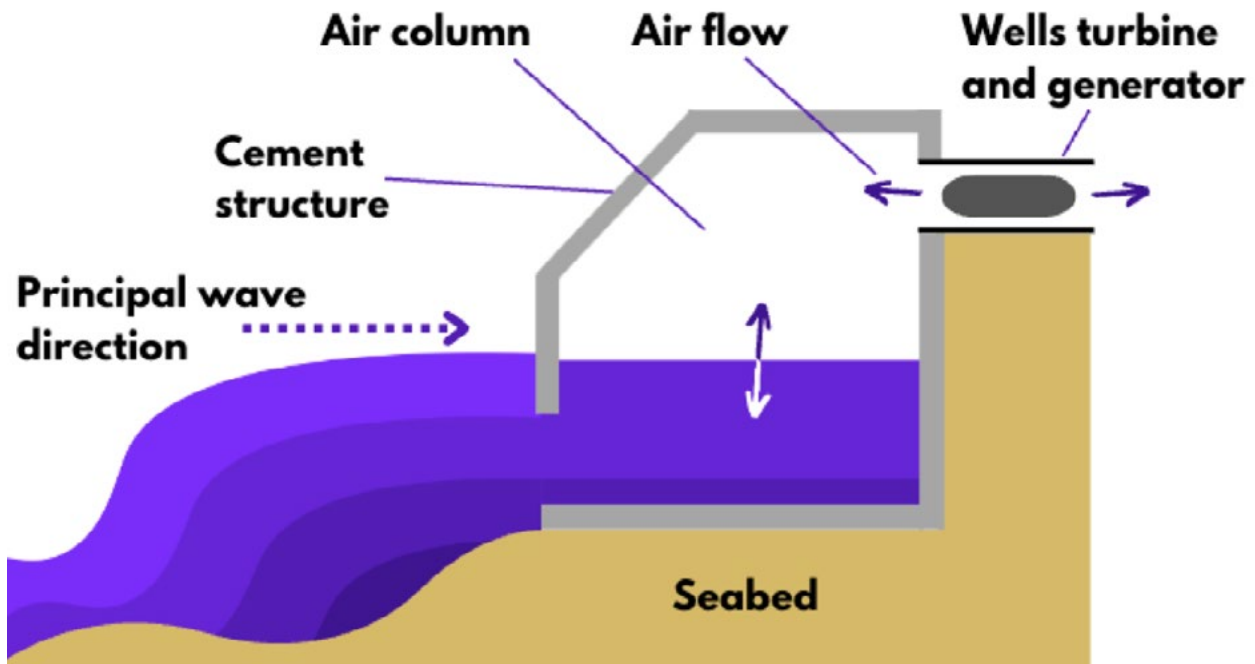
1. **Wave energy is a non-renewable energy source.**  
☐ TRUE    ☐ FALSE Answer: False.
2. **Wave energy is a clean source of electricity with no greenhouse gas emissions.**  
☐ TRUE    ☐ FALSE Answer: True.
3. **Wave energy is inconsistent and difficult to predict, making it unreliable for power generation.**  
☐ TRUE    ☐ FALSE Answer: False.
4. **Oscillating water columns are one of the technologies used to capture wave energy.**  
☐ TRUE    ☐ FALSE Answer: True.
5. **Wave energy devices can have a negative impact on marine ecosystems.**  
☐ TRUE    ☐ FALSE Answer: True.
6. **Wave energy is an established and widely used source of electricity around the world.**  
☐ TRUE    ☐ FALSE Answer: False.
7. **Wave energy can be converted into electricity through the use of hydraulic systems.**  
☐ TRUE    ☐ FALSE Answer: True.
8. **Wave energy is most effectively harnessed in locations with low wave activity.**  
☐ TRUE    ☐ FALSE Answer: False.

### Task 2: Single-choice test. Mark the correct answer

1. What technology for wave energy generation is shown in the picture below?

- ☐ a. Oscillating Water Column
- ☐ b. Overtopping device
- ☐ c. Attenuator

Correct answer: a



2. One of the advantages of wave power is?

- ☐ a. Well known technology
- ☐ b. Low cost of equipment
- ☐ c. Predictability

Correct answer: c

3. Where was the first wave energy installation built?

- ☐ a. USA
- ☐ b. Portugal
- ☐ c. Scotland

Correct answer: c

4. What is the primary mechanism through which overtopping devices generate wave energy?

- ☐ a. Directly capturing the up-and-down motion of waves
- ☐ b. Using hydraulic systems to convert wave motion
- ☐ c. Collecting and utilizing the water that spills over the device

Correct answer: c

5. What is the primary motion that point absorbers exploit to generate wave energy?

- ☐ a. Linear vertical motion
- ☐ b. Circular rotational motion
- ☐ c. Horizontal translational motion

Correct answer: a



Additional sources



## Reports

- ▶ IRENA (2020), Innovation outlook: Ocean energy technologies, International Renewable Energy Agency, Abu Dhabi.  
<https://www.irena.org/publications/2020/Dec/Innovation-Outlook-Ocean-Energy-Technologies>
- ▶ IRENA (2020), Fostering a blue economy: Offshore renewable energy, International Renewable Energy Agency, Abu Dhabi.  
<https://www.irena.org/Publications/2020/Dec/Fostering-a-blue-economy-Offshore-renewable-energy>
- ▶ IRENA (2021), Offshore renewables: An action agenda for deployment, International Renewable Energy Agency, Abu Dhabi.  
<https://www.irena.org/Publications/2021/Jul/Offshore-Renewables-An-Action-Agenda-for-Deployment>
- ▶ Tapoglou, E., Georgakaki, A., Letout, S., Kuokkanen, A., Mountraki, A., Ince, E., Shtjefni, D., Joanny Ordonez, G., Eulaerts, O. and Grabowska, M. (2022), Clean Energy Technology Observatory: Ocean Energy in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, doi:10.2760/162254, JRC130617.  
<https://op.europa.eu/en/publication-detail/-/publication/514586eb-50ef-11ed-92ed-01aa75ed71a1/language-en>
- ▶ IRENA and OEE (2023), Scaling up investments in ocean energy technologies, International Renewable Energy Agency, Abu Dhabi.  
<https://www.irena.org/Publications/2023/Mar/Scaling-up-investments-in-ocean-energy-technologies>
- ▶ Ocean Energy Systems (2023), Wave energy developments highlights.  
<https://www.ocean-energy-systems.org/publications/oes-brochures/document/wave-energy-developments-highlights-2023/>
- ▶ Ocean Energy Europe (2023), Ocean Energy. Key trends and statistics.  
<https://www.oceanenergy-europe.eu/wp-content/uploads/2023/03/Ocean-Energy-Key-Trends-and-Statistics-2022.pdf>

## YouTube films

- ▶ Harness the waves | National Geographic  
<https://www.youtube.com/watch?v=lwdtXGAtgvE&t=8s>
- ▶ Wave power could be energy's next big leap  
<https://www.youtube.com/watch?v=jahAum3zLsY&t=26s>
- ▶ How wave power could be the future of energy  
<https://www.youtube.com/watch?v=FxdbD-N7pHE&t=18s>
- ▶ CorPower Ocean deploys C4 Wave Energy Converter  
<https://www.youtube.com/watch?v=UdF8GpOFALQ>

## Websites

- ▶ Wave map  
<https://waves-energy.co/maps/>



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