Water and wind – traditional energy sources rediscovered

This guideline will provide an overview of the content and didactic context of the media in the media package entitled “Water and wind – traditional energy sources rediscovered.”

1 Introduction to teaching this topic

The practical significance of these topics is obvious, because only biomass has been used longer by mankind as a renewable energy source than water and wind power.
Depending on the type of school, hydropower and wind power appear in physics mandatory curricula between 7th and 12th grades. If the topics are not explicitly mandated, they are extremely well suited for use as current examples of principles in other mandatory curriculum topics from various fields such as power generation, power supply, energy conversion, generators, turbines, wind turbines, the Bernoulli Effect, flow, and electrical parameters. This media package also offers interfaces with geography instruction. Therefore, it supports teachers in covering standard material using two highly topical themes.
For a general introduction to the topic of renewable energy, you’ll find a media package entitled “Renewable energy – the future is sunny” on the media portal of the Siemens Stiftung. There is also another media package on the topic “Solar thermal energy and photovoltaics” at the same location.
As an introduction to the topics of hydropower and wind power, and as a quick reference, the teacher can use the guidelines in this media package.

Media	Guideline “Renewable energies”
	Guideline “Energy conversion”

The media files in the package can be used individually and completely independently of each other strictly by subject. However, the lesson will certainly be livelier when the media are used in context. The direct applicability of the material to the lives of the students creates an opportunity to spark students’ interest in specific technical details. To accomplish this, we recommend working through the topic in the following steps:

- **Water and wind – two very similar energy sources**
  Two proven energy sources with modern technology
  How do water and wind fit with other energy sources?
- **Hydropower**
  What is hydropower?
  Why are there different kinds of hydroelectric plants, and how do they work?
  The physics of water turbines
  Is it possible to expand hydropower with innovative power plant types?
- **Wind power**
  Underrated wind power
  How do wind power plants work?
  Frequency and phase – do wind power plants need a gearset?
  How does wind electricity fit into the grid?
- **A physical comparison of wind power and hydropower**
  Potential and kinetic energy in wind and water

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Wind and water turbines as resistance rotors or continuous flow machines (lift-type wind turbines)

2 Introduction: Water and wind – two very similar energy sources

2.1 Two ancient energy sources with modern technology

Humanity has long been taking advantage of both energy sources in the form of waterwheels (since approx. 2300 BC) and windmills (since approximately 600 AD). The modern incarnation of hydroelectric plants, used to generate power with water turbines, dates back to 1880. Wind power plants for the purpose of generating electricity were first popular for a brief time around 1900. Beginning in the 1980s, they quickly developed into technically mature solutions. Viewed from this perspective, wind and water are two renewable energy sources with no technical limits on rapidly expanding their use to replace fossil energy sources. The physics involved in the use of these energy sources in power plants is quite similar, and students can learn quite a bit about physics and technology from the differences and similarities.
To set the mood, here's a picture showing both energy sources together:

Medium	Photo "Wind power plant at sea"

(Hydropower only indirectly as tidal and wave power plants that are not visible in this photo; therefore, tides and waves in the ocean should be noted as energy sources.)

2.2 How do water and wind fit with other energy sources?

Students can think about which process is the ultimate source for all energy sources. The example with the tidal range is particularly didactically valuable for physics class, because at first glance, it seems to be a perpetual motion machine. Everyone will realize that the moon does the lifting work. But where did it get the energy to do that? Wherever energy is "gained" somewhere, it must be "lost" somewhere else.
A quick refresher on the topic of forms of energy and where and how much water is involved:

Media	Overview graphic "Renewable energy sources" Table "What type of energy can be found in which energy source?" Schematic diagram "Energy sources for electric power" Information module with charts "Power generation worldwide"

For preparation for teachers or as a basis for student presentations:

Media	Guideline "Renewable energies" Guideline "Energy conversion" Link list "Renewable energies"

3 Hydropower

3.1 What is hydropower?

With the exception of thermal water (geothermal) and the tides (moon, Earth's rotation), hydropower is based on the potential energy that comes from water masses that have been evaporated by the sun and redeposited as rain.

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Media Overview graphic “Water as an energy source”
Information sheet “Water as an energy source”

3.2 Why are there different kinds of hydroelectric plants, and how do they work?

As water that has fallen as rain makes its way to sea level, the potential energy it contains can be used to generate power at hydroelectric plants. There are different power plant types that are suitable for different types of geography. The run-of-river hydroelectric plant and the storage power plant are the two basic types discussed; the pump storage power plant is introduced as the man-made temporary energy storage solution. The tidal power plant (which uses the moon and Earth’s rotation as its energy source) and the wave power plant (which uses wind) are a bit different because of the energy sources they use, but the physics of these plant types is the same.

Medium Information module with animation “Hydroelectric plants”

To generate electricity from hydropower, you need turbines and generators:

Medium Photo “Turbines and generators in the Walchensee power plant”

3.3 The physics of water turbines

In a hydroelectric plant, the object is to convert as much of the water’s potential and kinetic energy as possible to rotational energy so that the rotation can drive a generator. Because this is a mechanical-energy-to-mechanical-energy conversion, it could theoretically achieve 100 percent efficiency. On a waterwheel, most of the water flows off the blade (overshot) or around the blades (undershot), so its efficiency is low. In contrast, the casing, additional jets or guide blades, and the shape of the rotor blades in the water turbine force all the water to flow against the turbine blades so that it can give off up to 95 percent of its energy. If you measure the sum of the potential energy ($= m \cdot g \cdot h$) and kinetic energy ($= 1/2 \cdot m \cdot v^2$) before and after the turbine, you’ll know how much of the water’s energy was successfully transmitted.
But how should you build the turbines to achieve optimal efficiency? Depending on the height of drop and amount of water, three basic types of water turbines have been developed that all achieve over 90 percent efficiency: Pelton, Francis, and Kaplan turbines.

Medium Information module with animation “The physics of water turbines”

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3.4 Is it possible to expand hydropower with innovative power plant types?

In the United States, much of the economically viable hydropower has already been exploited, but expansion and improvement of existing plants could increase utilization by about 10 percent. In Africa, Asia, and South America, however, only about 20 percent of the technically feasible hydropower has been harnessed. And in Germany and Central Europe, the potential for hydropower that can be used with conventional power plants is mostly exhausted. Traditional tidal power plants are also not economically feasible. Utilizing wave power provides additional options:

Media	Information module with animation “Hydroelectric plants” Labeled graphic “Wave power plant” Simulation “Pumped storage power plant”

Teaching idea: Project or presentation on the topic “If wave power plants were built along Germany’s coast, and water buoys, water propellers, or ‘shaft hydroelectric plants’ were placed in rivers and streams, how much could you increase the percentage of hydropower as part of overall power generation?”

4 Wind power

4.1 Underrated wind power

The wind socks placed at large viaducts remind you of the often untapped power of wind energy.

Media	Photo “Wind as an energy source” Photo “Wind turbine in landscape”

Severe, destructive storms are becoming more and more common throughout the world. What are the causes? What does that mean for the use of wind power to generate energy? Teachers could give these questions to the students as an inquiry task.

Medium	Inquiry task and link list “Storms and wind power”

4.2 How do wind power plants work?

We will discuss only propeller turbines with a horizontal axis of rotation – in a three-bladed version this is generally now the technical standard around the world. We will explain how they are built and talk about their efficiency, which cannot exceed 59.3 percent according to the laws of physics. We will also discuss the need to store energy, the best locations for wind power plants, and the potential of wind power.

Media	Information module “How a wind power plant works” Information module “Energy storage”

4.3 Frequency and phase – do wind power plants need a gearset?

A brief foray into electrical science makes it clear: to directly transform the wind power to feed it into the grid, it must have a frequency of exactly 50 Hz in synchronous phase. Just like the generators in thermal power plants or hydroelectric plants, single-pole generators would have to run at exactly 3,000 rotations per minute (rpm), two-pole generators would have to run at 1,500 rpm, etc. Because the wind “blows” at different speeds, however, conventional wind power turbines have

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controllable gearsets; some also have generators with a switchable number of poles. However, the latest technology first converts the alternating current from the generator to direct current; it is then changed back to alternating current at the exact frequency and phase of the grid and transformed into mains voltage. In this case, the gearset and switchable generators are not needed.

Media	Labeled graphic “Functional design of a wind turbine” Labeled graphic “Wind turbine – inside view” Photo “Generator for a wind turbine” Guideline “Energy conversion”

Note: The problem of the exact frequency and rotational speed of the turbine also exists in hydropower. The basic design of water turbines is already adapted to the water flow found at the site. Fine adjustment of the water flow is performed through automatic control of the guide blades and jets.

4.4 How does wind electricity fit into the grid?

While electricity from run-of-river and storage power plants is generally used to cover base load demand, wind power is not very well suited for this. It is possible to use wind power in combination with gas turbine power plants. Gas turbines can be added to compensate for any “missing” wind power, allowing wind to cover both base demand and peak demand. However, combining wind with natural gas goes against the concept of replacing fossil energies. This is why wind power, just like solar energy, must be combined with yet-to-be-developed energy stores. And the frequently quoted idea that “many small modular renewable power generation plants can supply energy for everyone on a distributed basis” doesn’t prove successful when it comes to power security (that would perhaps work for private households, but not for large industrial plants). Only a mix of central power supply with distributed power generation, combined with the feed-in and storage of renewable energies at both the centralized and distributed level, can solve the problem.

Medium	Schematic diagram “Central and distributed energy supply”

The existing natural gas network can be used for distribution and storage of gas produced through the conversion of excess wind and solar electricity to hydrogen or even methane (power to gas). A graphic illustrates the power-to-gas process. For example, vehicles with fuel cell technology could be driven using the hydrogen obtained in this process. A photo shows a fuel cell for (school) experiments.

Media:	Graphic “Power to gas” Photo “Fuel cell for experiments”

5 A physical comparison of wind power and hydropower

Depending on the grade level and mandatory curriculum, the topic of wind and hydropower could be explored in more depth.
For example, teachers could explain in more detail why wind and hydropower have such large differences in efficiency. To do this, they could, for example, work out the differences in the flow behavior of compressible media (such as air) and non-compressible media (water). They could mathematically derive Betz’ Law for the optimal efficiency of wind power as an optimization problem.

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Teachers would need to explain the difference between turbines as resistance rotors and continuous flow machines. With resistance rotors, the mass flow immediately presses the blade away in the direction of flow, a principle that is employed in the Pelton water turbine and in the Savonius wind turbine. In the continuous flow machine, the pressure differential between the front flow side and the back side of the blade profile causes the blade to evade in the direction of rotation – a principle embodied in Kaplan turbines (in water) and in windmills shaped like a propeller (in air). In contrast, the Francis turbine is a combination of both types. These topics can be taught along with the two information modules from the media package in conjunction with the two guidelines.

Media	Information module with animation “The physics of water turbines” Information module “How a wind power plant works” Guideline “Renewable energies” Guideline “Energy conversion” Link list “Renewable energies”

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