B6 Renewable energies

Subexperiment B6.1 Harnessing solar energy as heat (1)
Subexperiment B6.2 Harnessing solar energy as heat (2)
Subexperiment B6.3 Harnessing the energy of water
Subexperiment B6.4 Harnessing the energy of wind

1 Main question

The following questions underlie the subexperiments and guide the activities:

- What are renewable energies?
- What types of energy conversion are used in everyday life?
- What is solar energy?
- What is hydropower?
- How does a wind turbine work?

2 Background

2.1 Relevance to the curriculum

The topic of energy is being added to environmental experiments with the goal of educating students about sustainable development. It is becoming extremely important these days in the context of environmental protection. The keywords “resource poverty” and “renewable energies” in particular are gaining more and more attention.
For the students to be able to approach this complex topic, it is important that they be familiar with the various forms of energy conversion. All four subexperiments lay an important foundation for this understanding.
It is also important that the students work hands-on. The models they build themselves in the individual subexperiments allow the students to broaden previous experience while gaining new experience.

Topics and terms

Absorption, energy conversion, energy store, fossil fuels, hydropower, renewable energies, solar energy, solar power plant, solar thermal energy, wind power, wind turbine

2.2 Skills

The students will …

- come to understand that the sun, wind, and water are extremely important as sources of energy for a sustainable energy supply.
- analyze the factors that influence the use of these energy sources.
- recognize the functioning of technologies for harnessing solar energy, wind power, and hydropower.
- recognize the source of energy from which these renewable energies originate.

2.3 Preliminary information on renewable energies

In a strict scientific sense, the term “renewable energies” is incorrect. Energy can be neither created nor consumed, and thus it cannot be renewed. Energy can only be converted.
The energy for life on Earth comes basically from two main sources: The sun and (deep) geothermal energy. By human standards, these sources of energy are seemingly inexhaustible.

On the one hand, the sun’s radiant energy can be used directly, in solar thermal energy systems (see subexperiments 1 and 2) or by means of solar cells or photovoltaic systems (see Experimento | 8+ **A5 Solar cells**). On the other hand, solar energy is used indirectly via the energy contained in water and wind, since the sun causes the movement of water (see Experimento | 8+ **B1 Water cycle**) and the air layers (see Experimento | 8+ B4 “Wind”). Viewed in this way, these forms of energy can be justifiably referred to as renewing themselves. Hydropower and wind energy are examined more closely in subexperiments 3 and 4. Biomass represents a special case: It is considered to be the only source of renewable energy in which solar energy is naturally present in a stored form after it has been converted to chemical energy through photosynthesis.

The main source of renewable energy on Earth is sunlight. Measurements outside our atmosphere have shown that the sun radiates energy totaling 1.37 kilowatts per square meter (1.37 kW/m^2) to the Earth. Most of this energy, about 1 kW/m^2, reaches the Earth’s surface (when the sun is directly overhead). If we multiply this number by the number of hours per year (8,760 h/a), we determine that the sun provides a volume of energy totaling approx. 8,760 kWh/m^2 per year. Of course, the sun does not shine 24 hours a day in the same location. In addition, a large part of the Earth’s surface is ill-suited for harnessing solar energy through photovoltaics or solar thermal energy.

In Germany in 2014, the average four-person household needed approx. 4,400 kWh of electrical energy (source: “Stromspiegel 2014,” German Federal Ministry for the Environment, et al.), which is less than half the energy radiated by the sun to every single square meter.
If we consider the total annual power consumption of a country as well as technical details, such as the efficiency of solar cells and the optimal alignment toward the sun, we can calculate how large the total surface area of solar cells would have to be in order to cover the total electricity requirement of a country using solely photovoltaic systems. For Germany, the calculation is based on gross electricity production of 634 TWh in 2013 (source: German Federal Environment Agency) and results in a solar cell area of 1.5 – 6% of Germany’s total surface area.
That seems like a large area at first glance. However, if you consider how much area in Germany is already developed and the fact that the facades and roofs of factory buildings, office buildings, etc., can also be used, it isn’t very much. Nonetheless, in order for electricity to be supplied exclusively via photovoltaics, sufficient intermediate storage capacity for the generated electricity would have to be established.

Energy storage is an important topic, especially in connection with renewable energy. The sun and wind are not always available. Until now, the energy from water has been continuously available in most hydroelectric plants. In times of climate change, however, periods of low water levels and flooding are becoming increasingly frequent. As a result, either not enough water is available or too much available water goes unused.

There are two reasons why renewable energies are being used more often:

- The first reason is the greenhouse effect, or climate change. To slow this down, the emissions of the greenhouse gas carbon dioxide (CO_2), which come mainly from the combustion of fossil fuels, have to be greatly decreased.
- The second reason is that fossil energy sources are becoming increasingly scarce. It seems that the resources may still last for a very long time, but all deposits that can be exploited easily and cost-effectively are being rapidly depleted and the risk and costs of further exploitation are increasing disproportionately. All this already makes these energy sources unaffordable in the medium term. In contrast, the wind and sun are available for free.

3 Additional information on the experiment

You will find additional media for preparing or for further study of this experiment on the Siemens Stiftung Media Portal: https://medienportal.siemens-stiftung.org

4 Conducting the experiment

Notes:

- The listed materials are designed to allow **one** group of maximum **five** students to conduct the experiment.
- Terms: The term “power plant” is historical. Actually, power plants are energy conversion plants. In a hydroelectric plant, for example, the kinetic energy of the water is converted to electrical energy.
- The energy concept that these subexperiments are based on is explained in detail in the “Electric current and energy – Basic physics principles and models” handout (chapter 7 ff.), which is found in the guidebook for Experimento | 8+.
- The topic of energy storage is explained in the technical background information for teachers to the extent that it is relevant in the context of renewable energies. Energy storage is not addressed in the experiments for students.

4.1 Subexperiment B6.1 Harnessing solar energy as heat (1)

4.1.1 Required materials

Material	Quantity
Adhesive tape	1
Construction paper, black	1
Construction paper, white	1
Plastic bottle with cover	2 per group
Thermometer	1
Water, lukewarm	Enough to fill both bottles

4.1.2 Organizational aspects

Facilities	In the classroom at a sunny windowsill or outdoors (direct sunlight is necessary)
Time required	Approx. 45 minutes Ideally, subexperiments B6.1 and B6.2 should be conducted one right after the other (90 minutes total). Depending on the intensity of the sunlight, the two experiments may not be entirely successful until the end of a class period.
Safety instructions	See the “Safety instructions on the topic of the environment” in the guidebook.
Cleanup	The plastic bottles should be recycled.

4.1.3 Explaining the subexperiment in the teaching context

The students will learn what object color best absorbs sunlight. They will apply this knowledge to heat water using sunlight and black paper.

Technical background

Sunlight is absorbed by the black paper. The radiant energy of the light is converted to thermal energy (heat) in the paper. This heat is transferred through the wall of the plastic bottle and to the water. This heat transfer takes place when the molecules in the black paper collide with the molecules in the wall of the plastic bottle. In turn, these molecules collide with the water molecules (principle of heat conduction) In addition, the heat is distributed throughout the water by means of circulation (convection). Furthermore, the warm black paper itself emits longwave electromagnetic radiation (principle of temperature radiation or black body radiation). The water largely absorbs this longwave radiation and is heated even more.
A device that converts solar energy to heat according to this principle is called a **solar collector**. These solar collectors are found on rooftops, for example, to heat non-potable water in households. They range from a simple black drum to a high-tech system with metallic black absorber pipes under a glass surface.
However, the method applied in this subexperiment can also be used to store solar energy. In addition to water, stone, concrete, and brick are also used to store heat. (For other storage technologies, see section 4.2.3.)

4.1.4 Ask about the students’ prior knowledge and ideas

The students can report on where they have experienced surfaces heated by the sun in everyday life. The students may have experienced that they sweat more easily in summer when they wear dark-colored clothes rather than light-colored clothes. While on vacation in some southern countries, they may have seen black drums installed on rooftops of homes. These drums are used to heat water.

4.1.5 The research cycle

Important aspects and information regarding the individual process steps of the research cycle during the experiment for students:

Recognizing the problem/phenomenon	In this experiment, the students will learn how sunlight can heat water.
The research question	The following alternatives to the research question stated in the student instructions are possible: ▪ Why do we wear dark clothing in winter? ▪ Why are houses in some southern countries painted white?
Collecting ideas and guesses	Some possible guesses: **Related to the research question:** "It isn't possible to heat water without electricity." **Related to the experiment:** ▪ "Water can be heated using paper." ▪ "The water in the bottles warms up only very slowly." ▪ "The paper's color doesn't make a difference in heating." ▪ "The sunshine has no influence on the water." Segue from the guesses to the experiment.
Experimenting	**Experiment setup:** ▪ Direct sunshine is important since the experiment will otherwise take much longer. However, for the students to be able to measure a temperature effect, the thermometer itself must not be exposed to direct sunshine. ▪ Make sure that the students wrap the paper as tightly as possible around the bottles. ▪ To keep within the time frame, the students should fill the bottles about one-fourth, maximum halfway, with lukewarm water. **Conducting the experiment:** Encourage the students to be patient and diligent since the experiment depends on the sunshine. The results may vary greatly depending on the time of day and season.

Observing and documenting	**Most important observations:** ▪ When the students measure the temperature of the paper, they will determine that there's a difference between the two sheets of paper: the black paper becomes very warm, while the white paper does not. ▪ The water temperatures in the wrapped bottles increase at different rates. In the bottle wrapped in black paper, the water heats up faster and higher than in the bottle wrapped in white.
Analyzing and reflecting	**The most important results:** ▪ The water in the bottle wrapped in black heated up faster. ▪ The white paper reflected a lot of sunlight. As a result, the paper heated up a little. The paper transferred a little of the heat to the bottle. The black paper absorbed a lot of sunlight. As a result, the paper heated up a lot. The paper transferred a lot of heat to the bottle. ▪ The students will learn that in order to harness solar energy, it is important not only to capture the sunlight, but also to transfer the energy to the relevant medium (in this case, water). This means that as much of the radiant energy as possible must first be converted to heat and then this thermal energy must be transferred to the water medium. The closer the contact between the heated paper covering and the bottle contents, the better the heat conduction and the more the water will be heated. **Reference to the story to get the students thinking about the topic:** Now you know why you become especially warm with the dark jacket. The sun's heat is stored far better in dark objects than in light objects.

4.1.6 Further information

In the student instructions

Doing further research	Solar collectors that are installed on rooftops to heat water are built as flat plate collectors or tube collectors. The main differences are in the way the absorber material is installed and in the insulation. Tube collectors are more expensive, but also more efficient. Point out the difference between solar collectors and photovoltaic systems to the students in this context. Both can be seen on rooftops. While solar collectors convert the solar energy to heat, photovoltaic systems convert solar energy to current.

Miscellaneous

The experiment showed how solar energy can be converted to heat in water. In a class discussion, the students can be instructed in how this knowledge can be used for energy storage. They will probably make a reference to the fact that warm water can be kept in an insulated container, such as a Thermos bottle, and so warm water is available even when the sun is no longer shining.

4.2 Subexperiment B6.2 Harnessing solar energy as heat (2)

4.2.1 Required materials

Material	Quantity
Aluminum foil	1
Burning mirror	1
Cardboard or thick paper, standard letter size	2 per group
Plastic bottle with cover	2 per group
Modeling clay	1
Sunglasses	1
(Stop) watch	1
Thermometer	1
Water (lukewarm)	Enough to fill the bottles

4.2.2 Organizational aspects

Facilities	Outdoors, because direct sunlight is necessary
Time required	Approx. 45 minutes Ideally, subexperiments B6.1 and B6.2 should be conducted one right after the other (90 minutes total). Depending on the intensity of the sunlight, the two experiments may not be entirely successful until the end of a class period.
Safety instructions	See the “Safety instructions on the topic of the environment” in the guidebook. Take precautions against damage from sunlight (blinding of the eyes, burns from hot objects).
Cleanup	The plastic bottles should be recycled.

4.2.3 Explaining the subexperiment in the teaching context

The students will heat water again with sunlight, this time using homemade mirrors. They will learn how the bundling (concentration) of sunlight heats the water to a higher temperature faster.

Technical background

The sunlight is bundled by the mirrors and concentrated on one position, called the focal point or focal plane. High temperatures are produced at this position, thereby heating an absorber (water in this experiment): The solar energy is thus also converted to heat using this technology (compare subexperiment 1).

Application in power engineering: A facility for generating electric power by converting solar energy to heat, according to the aforementioned principle, is called a **solar power plant**. This principle can be clearly explained using a parabolic trough power plant as an example: A pipe (“absorber”) with a working medium (for example, oil) runs along the focal points of a long row of parabolic reflectors. The reflectors are automatically aligned to follow the path of the sun. The radiation is intensified 80-fold due to the bundling in the reflectors, and the oil in the absorber is heated to around 400°C. The hot oil flows to the power plant building, where it generates steam via a heat exchanger to drive a steam turbine with a generator. Parabolic trough power plants generate electricity in the output range of large coal-fired power plants. One example is the Andasol 1 – 3 solar thermal power plants that are located in the southern Spanish province of Granada. Each module has a power plant output of 50 MW. Thanks to integrated heat storage, the power plant continues to run for over seven hours at full output even when the sun is not shining.

A device called a latent heat store is often used to store energy in this type of power plant. Part of the solar energy is used during the day to change the state of aggregation of a salt from a solid to a liquid. When the salt melts, it absorbs energy, which it releases again when it solidifies. The released heat can then be used to generate steam and to operate a turbine and a generator for electric power generation.

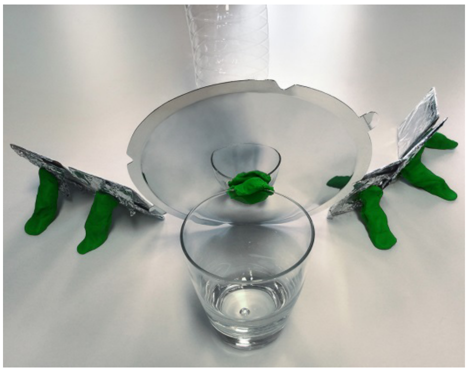
4.2.4 Ask about the students' prior knowledge and ideas

In subexperiment 1, the students learned that sunlight contains energy that can be converted to heat in a suitable absorber. Perhaps they have already seen sunlight reflecting in a mirror and know that when this reflection is aimed at one point, it produces a high temperature at that point (focal point) and can cause objects to ignite. If they have this prior knowledge, they can draw the conclusion that numerous aligned mirrors can heat water, for example, more quickly than just one mirror.

4.2.5 The research cycle

Important aspects and information regarding the individual process steps of the research cycle during the experiment for students:

Recognizing the problem/phenomenon	In this experiment, the students learn how sunlight can be collected and stored using mirrors.
The research question	The following alternatives to the research question stated in the student instructions are possible: ▪ What options do your parents have for heating the pool water with solar energy?

Collecting ideas and guesses	Some possible guesses: **Related to the research question:** ▪ "The energy of the sun is difficult to capture." ▪ "The light of the sun heats up the water." **Related to the experiment:** ▪ "Water isn't suitable for storing solar energy." ▪ "It takes hours for the sun to heat up the water even just a little." ▪ "The mirrors work like a type of amplifier." ▪ "The number of mirrors doesn't influence the heating process." ▪ "The aluminum foil should store the heat, just like in the kitchen when I want to keep my food warm." Segue from the guesses to the experiment.
Experimenting	**Experiment setup:** ▪ So that the mirrors do not block each other in the setup, the students should position the bottle somewhat higher. To do this, they could use a stack of two or three books, for example.  Fig. 1: Experiment setup from behind showing the holders for the mirrors. ▪ Provide assistance when the students align the mirrors to greatly reduce the duration of the experiment and to keep the students from becoming frustrated. ▪ Cardboard or modeling clay is a suitable material for making a stand for the burning mirror. A glass can also be used. ▪ It can also be helpful to reduce the amount of water, since a smaller amount can be heated faster. **Conducting the experiment:** ▪ While some students are conducting the measurements, the other group members should carefully document the measurement results. ▪ The experiment requires patience since it greatly depends on the weather. The radiation intensity also depends on the season and time of day. ▪ The students will determine that it is not so easy to align the mirrors to optimally aim the sunlight on the bottle.

Observing and documenting	**Most important observation:** The temperature of the water in the bottle surrounded by mirrors will rise faster and higher over a period of 9 minutes than will the temperature of the water in the bottle without the mirrors.
Analyzing and reflecting	**Results to be expected:** 1. Based on the measured temperatures, it quickly becomes clear that the water in the bottle that the burning mirrors are focused on heats up faster than the water in the bottle that's simply in the sun. 2. The students will recognize that the burning mirrors' purpose is to bundle the sunlight and concentrate it on a focal point. 3. The solar energy is converted to heat in the wall of the plastic bottle and in the water. **Reference to the story to get the students thinking about the topic:** To heat the pool, your parents could have a couple of mirrors installed at the side to reflect the sunlight and direct it into the water.

4.2.6 Further information

In the student instructions

Doing further research	A prerequisite for carrying out this research project is that the students be familiar with the principle of electric power generation in large power plants: Electric power is generated using steam that drives a turbine, which in turn drives a generator. Since it can be assumed that the students are not yet familiar with turbines and generators, the teacher must explain these devices in advance, or the students must research them online. The students should apply their knowledge of this familiar system in order to transfer it to the findings from the experiment and to think about how they can "generate" electric power from solar energy. In order to do this, they would have to heat the water on which the sunlight is being aimed with the mirrors until it steams (see section 4.2.3).

Miscellaneous

A modified variation of this experiment would be a setup in which a bowl (or a similar object) is covered with aluminum foil and the object to be heated is attached in the middle (principle of a "solar cooker"). As a result, the students will have modified the design, but the results of the experiment will still be comparable with those of the original setup.

4.3 Subexperiment B6.3 Harnessing the energy of water

4.3.1 Required materials

Material	Quantity
Container with a hole in the bottom	1 per group
Large plastic container	1 per group
Drinking straw	1
Modeling clay	1
Packing tape, brown	1
Thin cardboard or thick paper, 2 x 6 cm	6 strips per group
Thick tubing, approx. 50 cm long	1
Wooden skewer	1
Wristwatch with a second hand	1 watch per 2 groups
Water – at least three times the amount that fits in the container with the hole	

Material for the additional experiment	Quantity
Object (small stone, piece of wood, etc., relatively lightweight)	1
String	Approx. 30 cm per group

4.3.2 Organizational aspects

Facilities	In the classroom or outdoors Access to water is required. The surroundings should be able to withstand splashed water.
Time required	Approx. 45 minutes To minimize the length of time needed, the teacher can prepare the cardboard or paper strips for making the waterwheel by covering them with packing tape.
Safety instructions	See the “Safety instructions on the topic of the environment” in the guidebook.
Cleanup	The students can take their waterwheels home. If the waterwheels are disposed of, the materials should be properly separated.

4.3.3 Explaining the subexperiment in the teaching context

The students will build a small waterwheel. The wheel is driven by water flowing through tubing from a container held at different heights. By varying the height of the container above the waterwheel, the students will recognize what effect the height of drop has.

Technical background

In this subexperiment, a waterwheel is set in motion by means of a stream of water. In the additional experiment, a small object is lifted by the waterwheel. The latter is a good example of work (= lifting) being done with the water’s energy.
The energy conversion is from one form of kinetic energy (linear movement of water) to another form of kinetic energy (rotary motion of the wheel). The water’s kinetic energy results from its potential energy, which results from the water's force due to its weight (gravity force) and the water’s height above the ground.

Application in power engineering: Water as an energy source has the advantage that it is found on Earth in large quantities and is available day and night.
A facility for generating electric power by converting energy from flowing water to electric power, according to the aforementioned principle, is called a **hydroelectric plant**. The experiment setup is basically comparable to a storage power plant. In this type of power plant, water flows through a downspout from a great height, giving it kinetic energy. The greater the height of drop, the more energy the water has when it hits the waterwheel (turbine). The water’s energy is converted to kinetic energy of the turbine, which in turn drives a generator that converts the kinetic energy to electrical energy.
In addition to storage power plants, there are other types of hydroelectric plants that depend on natural conditions, such as run-of-river power plants on rivers and tidal power plants on seashores. The kinds of turbines used are also adapted to these conditions. Kaplan turbines are used in run-of-river power plants, which have a relatively large volume of water but only a slight height difference; Francis turbines are used in storage power plants with large volumes of water and great heights of drop; and Pelton turbines are used for small volumes of water and very large heights of drop. These turbines are each named after their inventors.
A particular design of hydroelectric plant, called a pumped-storage power plant, is used as the energy store. In periods of excess electricity, the energy is used to pump the water to a reservoir at a higher position. At times of peak demand, the power plant then works like a normal storage power plant.

4.3.4 Ask about the students’ prior knowledge and ideas

In this experiment, the students will determine that the water’s energy depends on the volume, the position, and the speed of the water. The more water that flows, the greater the force when it reaches the waterwheel (turbine); similarly, the greater the height from which it falls and the greater the speed of the water, the more energy it gains. Some students will certainly know from experience that when a container is filled at the tap, the water can spray over the edge of the container when the tap is opened too far. From playing with water balloons, many students may be familiar with the fact that the greater the height from which the water balloon falls, the greater the effect.

4.3.5 The research cycle

Important aspects and information regarding the individual process steps of the research cycle during the experiment for students:

Recognizing the problem/phenomenon	This experiment is about becoming familiar with water as an energy source.
The research question	The following alternatives to the research question stated in the student instructions are possible: ▪ How can you “produce” energy with water? ▪ Where is water used as an energy source?
Collecting ideas and guesses	Some possible guesses: **Related to the research question:** “The water’s energy can be used only if the water moves.” **Related to the experiment:** ▪ “Building the waterwheel is complicated.” ▪ “The wheel is set in motion by the water.” Segue from the guesses to the experiment.
Experimenting	**Experiment setup:** ▪ The complex experiment setup is made easier for the students if the teacher brings a homemade model to show what the waterwheel should look like (see figure 2). Without a model, they will need some assistance, since attaching the cardboard or paper strips could be difficult. ▪ The cardboard or paper strips should be covered very carefully with strips of tape (maybe add additional tape to the cut edges), since otherwise they can quickly become soggy and the waterwheel can be used for only one round. The strips could be prepared by the teacher. ▪ The teacher can show the students how far the paper strips must be bent to tape them to the waterwheel. Alternatively, the students can also use paper strips 12 cm long, fold them in the middle, bend the open ends to each side, and tape the two ends to the drinking straw (see figure 3).

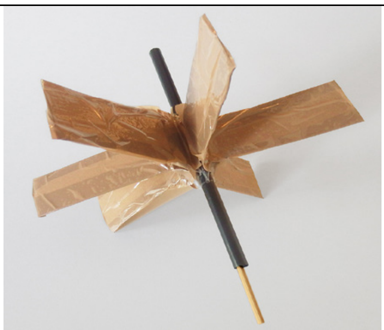
<table>
<tr><td></td><td>


Fig. 2: Completed model for the waterwheel.

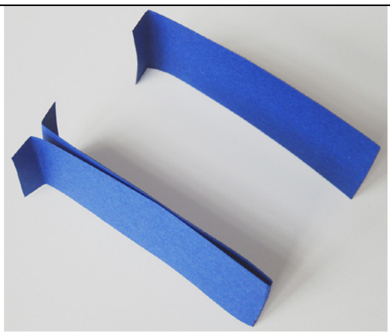


Fig. 3: Two variations of how the waterwheel blades can be folded.

Conducting the experiment:

- The students should work in groups of at least two.
- The direction in which the tubing is held or attached to the edge of a table or similar surface must be the same for all experiments. Provide assistance if necessary.
</td></tr>
<tr><td>

Observing and documenting
</td><td>
The students will try out various distances between the water container and the waterwheel.

Most important observations:

- The waterwheel rotates.
- When the container of water is held higher or lower, the wheel rotates faster or more slowly.
- When the stream of water stops flowing, the waterwheel continues to rotate briefly and then stops.
</td></tr>
<tr><td>

Analyzing and reflecting
</td><td>
The students will exchange views about the observed differences. They should notice that the stream of water has more energy to drive the waterwheel as the height of drop is increased.

Results to be expected:

1. The higher the water tubing is held, the faster the waterwheel rotates. The lower it is held, the slower the waterwheel rotates.
2. When the stream of water stops flowing, the waterwheel stops rotating.
3. The students should use their own words to describe the energy conversion chain shown below.

Potential energy of the water → Kinetic energy of the water → Kinetic energy of the waterwheel

4. A stone that falls from a height of 1 m leaves a larger crater in the sand than does a stone that falls from a height of 10 cm.

Reference to the story to get the students thinking about the topic:

Now you know that the energy of the water can be converted to current using the waterwheel. This current can then be used.
</td></tr>
</table>

4.3.6 Further information

In the student instructions

Doing further research	The students will test whether an object that is attached with string to the waterwheel's axle rises, and how far. They will recognize that the object is lifted higher the longer the wheel rotates. The rotating waterwheel performs work on the object. When the water flow stops and the wheel is no longer being driven, the object moves downward again. For a long time, people have applied the principle described here to generate electric power, ranging from watermills for grinding grain to hammer mills and hydroelectric plants. By completing the research project, the students will grapple with the technical application of a scientific principle that also had significant impacts on societal development and industrialization (for example, settlement on rivers, building of dams).

Miscellaneous

- Together with the students, consider how a waterwheel could work even better and what it would look like, and repeat the series of experiments together. A waterwheel can also be made from plastic parts, for example, from yogurt containers and waterproof glue.
  Build and test the waterwheels together with the students to strengthen the sense of community.
- Through further experimentation with the water's height of drop (without the waterwheel), the students will determine that the stream of water sprays farther as the height increases since the water exits the tubing at a higher speed. They should think about how this information can be transferred to real hydroelectric plants. Power plants with a Pelton turbine have a height of drop of up to 2,000 m, which means a lot of energy is available even with a small amount of water.

4.4 Subexperiment B6.4 Harnessing the energy of wind

4.4.1 Required materials

Material	Quantity
Adhesive tape	1
Cardboard tube	1 per group
Drinking straw	1
Glue	
Scissors	1
Tea bag	2 per group
Thin cardboard, 15 x 15 cm	1 per group
Thumbtack	1
Various colors of construction paper and master copy on page 20	1
Wooden skewer	1

4.4.2 Organizational aspects

Facilities	In the classroom or outdoors
Time required	Approx. 45 minutes
Experimental variation	Instead of using a drinking straw and wooden skewer, the students can use a pencil; instead of the tea bag, they can use a piece of string (approx. 30 cm) and attach a small, lightweight object to it.
Safety instructions	See the “Safety instructions on the topic of the environment” in the guidebook.

4.4.3 Explaining the subexperiment in the teaching context

The students will build a wind turbine in order to lift an object (tea bag) with it. They will operate the wind turbine by blowing on it.

Technical background

The energy conversion chain is similar to the conversion chain in hydropower, except that the energy source is wind rather than water.

Application in power engineering: A facility for generating electric power by converting energy from wind to electric power is called a **wind power plant**.
The most common design for large wind power plants is a three-bladed wind turbine with a horizontal axis of rotation. The wind turbine consists of a rotor and a nacelle, which are installed on a high tower (approx. 100 to 130 m). An anemometer and a computerized controller ensure that the wind turbine is always optimally aligned to the wind.
The wind turbine’s rotor blades can be up to approx. 75 m long. The wind turbine rotates (approx. 20 rotations/min) and turns the drive shaft. The gearbox converts the rotor’s rotational speed to the speed necessary for the generator, which generates the current. This current is conducted to the base of the wind turbine via cables.
A brake is used to keep the wind turbine from rotating, such as in severe storms or for servicing.

Like the sun, wind is not always available. For this reason, an energy store is also needed for wind energy. Pumped-storage power plants and compressed-air stores, for example, are under discussion.
In the latter, excess energy is used to compress a gas. At times of peak demand, this compressed gas can then be fed directly into compressed-air turbines; combustion of the gas and steam generation for the turbine are not necessary. Another chemical energy store that has been field-tested for both solar electricity and wind energy is “power to gas.” In this technology, the excess electricity from renewable energies is used to obtain hydrogen gas from water through electrolysis. Electricity can be generated again as needed with gas turbines or fuel cells using this hydrogen. However, methane (“natural gas”) can also be obtained from hydrogen and carbon dioxide using catalysts and can then be fed into the general natural gas network. The advantage of doing this is that an existing distribution and storage network for energy is available to be used as an extensive natural gas network. Another type of chemical energy store is a rechargeable battery. The batteries are charged using electricity from renewable energies during times of surplus and discharged during shortages. They are already mass-produced for use in households with photovoltaic systems. They are also currently being tested on a large scale in pilot projects to stabilize the power supply grid.

4.4.4 Ask about the students’ prior knowledge and ideas

The students do not need any particular prior knowledge. but certainly some students will be familiar with windmills, either they are wind turbines on a nearby field or pinwheels for having fun. It is also advantageous for the students to have basic experience with arts and crafts so that it is easier for them to assemble the wind turbine.

4.4.5 The research cycle

Important aspects and information regarding the individual process steps of the research cycle during the experiment for students:

Recognizing the problem/phenomenon	This experiment is about becoming familiar with wind as an energy source.
The research question	The following alternatives to the research question stated in the student instructions are possible: ▪ How can wind be converted to energy (current)? ▪ How does wind “produce” energy? ▪ Why does a wind turbine rotate? ▪ How does a wind turbine work?

Collecting ideas and guesses	Some possible guesses: **Related to the research question:** ▪ “The wind moves the wind turbine.” ▪ “The wind turbine cannot be set in motion by the wind alone. Electricity is also needed.” ▪ “Strong wind (a storm) has a lot of power.” **Related to the experiment:** ▪ “The harder you blow, the more energy is transferred to the wind turbine.” ▪ “The wind turbine cannot lift the weight.” Segue from the guesses to the experiment.
Experimenting	**Experiment setup:** ▪ The students will cut out the template as described and build their own wind turbine. ▪ The model built in advance by the teacher makes implementation easier for the students. **Conducting the experiment:** The students should vary how hard they blow the turbine.
Observing and documenting	**Most important observations:** ▪ The tea bag or other object is lifted as soon as the students blow on the wind turbine. ▪ If they blow harder, the wind turbine rotates faster and the tea bag or other object is lifted faster. ▪ If they stop blowing, the tea bag drops down again.
Analyzing and reflecting	**Results to be expected:** 1. The kinetic energy of the wind is converted to the kinetic energy of the wind turbine and the tea bag is lifted up. 2. Blowing harder: turbine rotates faster, heavier object can be lifted. Blowing more lightly: opposite result Two tea bags: The students must blow harder so that the turbine rotates and the tea bags are lifted. No tea bag: Blowing lightly is enough to rotate the turbine. The students will draw conclusions about the force of blowing (wind energy). By changing the size of the rotor blades and the object (lighter or heavier), they will recognize that the efficiency of the wind turbine can be changed and therefore the amount of energy produced will vary. **Reference to the story to get the students thinking about the topic:** Now you know how wind turbines must be built so that the wind can be converted to energy. Electrical energy is produced.

4.4.6 Further information

In the student instructions

Doing further research	By researching where wind energy can best be harnessed, the students will recognize that the use of wind energy depends on the location and requires exact planning and an expanded power supply grid.

Miscellaneous

When you have studied the individual details of the wind turbine together with the students, it is useful to approach the topic again more freely. The students now know what the purpose of a wind turbine is and which components are needed. Encourage them to consider their own designs for wind turbines. First, simply let the students create construction sketches and then consider together what building materials are needed. Then, based on the sketches, build the wind turbines together. Encourage the students to discuss their wind turbines and the underlying concepts with each other.

Master template

Wind turbine

- Cut out the outer circle and cut into the circle along the bold solid lines to the perpendicular line just before the inner circle.
- Also cut along the bold perpendicular lines.
- For each rotor blade, fold one half as indicated by the dotted lines.