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Odyssey
Oxford Debates for Youths in Science Education

Wind power plants are the best renewable energy source in mid-latitudes

Educational package

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Preface

The following educational package consists of two parts. The first one provides basic information on the topic of the debate.

In the second part you will receive tips on how to directly prepare for the discussion, in particular how to prepare arguments supporting or contradicting the following thesis:

Wind power plants are the best renewable energy source in mid-latitudes

INTRODUCTION

Wind, i.e. an orderly movement of molecules in the atmosphere, is caused by the pressure difference in two adjacent regions. This difference is called a gradient, and it primarily originates from the differences in the heating of seas and land by the solar radiation. So the Sun is the primary energy source that drives the movements in the Earth's atmosphere. Scientists estimate that only 1-2% of the Sun's energy that reaches the surface is turned into wind energy. Even this tiny fraction is, on the scale of the entire planet, a power of 3 PW (petawatts - million gigawatts). A constant supply of power reaching the atmosphere means that the wind energy will not run out - we say it is renewable.

Unfortunately, most of the wind energy is available in places too remote or too high for us to use. Winds blowing in regions that make it commercially viable to install wind farms, both above the land surface and in coastal areas, have energy potential of 60 TW (terawatts - thousands of gigawatts). For comparison, the average global energy consumption in 2019 did not exceed 3 TW.

Think about it and answer the following questions:

1. 1. How many times more energy can we recover from wind in relation to global consumption in 2019?
2. We said that energy from the Sun is constantly being supplied to the earth's atmosphere. However, the wind speed does not increase forever - the average wind speed for the entire planet is approximately constant. What does the kinetic energy associated with air movement convert into?
3. DIFFICULT! - Assuming a 3% annual increase in energy demand, in how many years the total demand of our civilization will equal the total energy available from wind.

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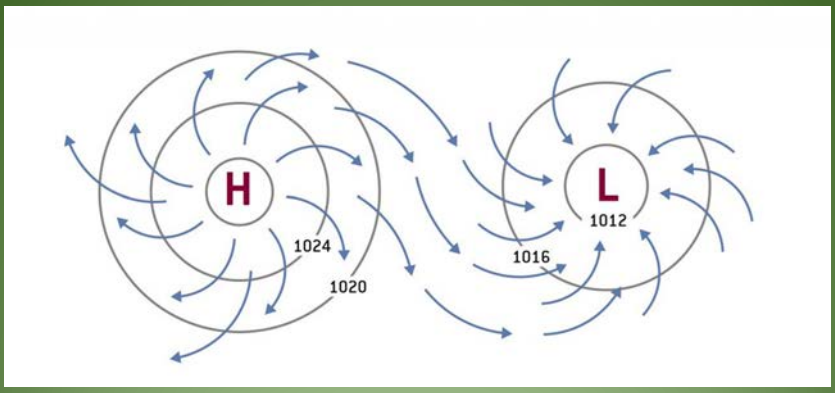
HIGHS and LOWS

The pressure gradient is the source of the force that drives the movement of air in the atmosphere. However, this does not mean that the movement is not governed by other coexisting effects.

The Earth is, approximately, a rotating ball. If we bind our frame of reference to it (which we usually do), we will be able to observe additional - apparent forces affecting the movement of bodies at the surface.

The Coriolis effect is the apparent force that causes deviation from a straight path. The direction of the deviation depends on the hemisphere in which we are located. North of the equator, the path of moving objects curves to the right. The air moving from high to low is going in a spiral, not in a straight line as you might think. This makes the path that the air mass has to travel significantly longer, therefore prolonging a life time of the low and high pressure systems. In the vicinity of the equator, where the Coriolis effect is negligible, no highs or lows persist, and hence no weather cycles known from mid-latitudes are observed.



Curvature of air paths in the Northern Hemisphere. H - high, L - low

Think about it and answer the following questions:

1. Which direction are hurricanes (low-pressure systems) turning towards in the southern hemisphere?
2. DIFFICULT! - do the tornadoes always turn in the same direction (in a given hemisphere)?

RENEWABLE ENERGY SOURCES

Renewable energy sources are those energy sources that become renewed in a relatively short time - up to the order of decades. Such sources include wind, solar radiation, rainfall, tides, sea waves, energy crops and geothermal energy. For comparison, we consider non-renewable sources as those that regenerate very slowly or not at all: e.g. crude oil, coal, natural gas and uranium obtained from minerals.

Due to the increasing global awareness of the problem of global warming, the governments of many countries have introduced systems of subsidies and incentives for investments in renewable energy sources. These investments are the subject of an ongoing debate. Renewable energy advocates point to the problems associated with burning fossil fuels, which are the source of about 80% of human energy: environmental pollution, global warming and resource depletion. Their opponents point to high costs, volatility in energy production, additional environmental costs and a questionable impact on the use of fossil fuels.

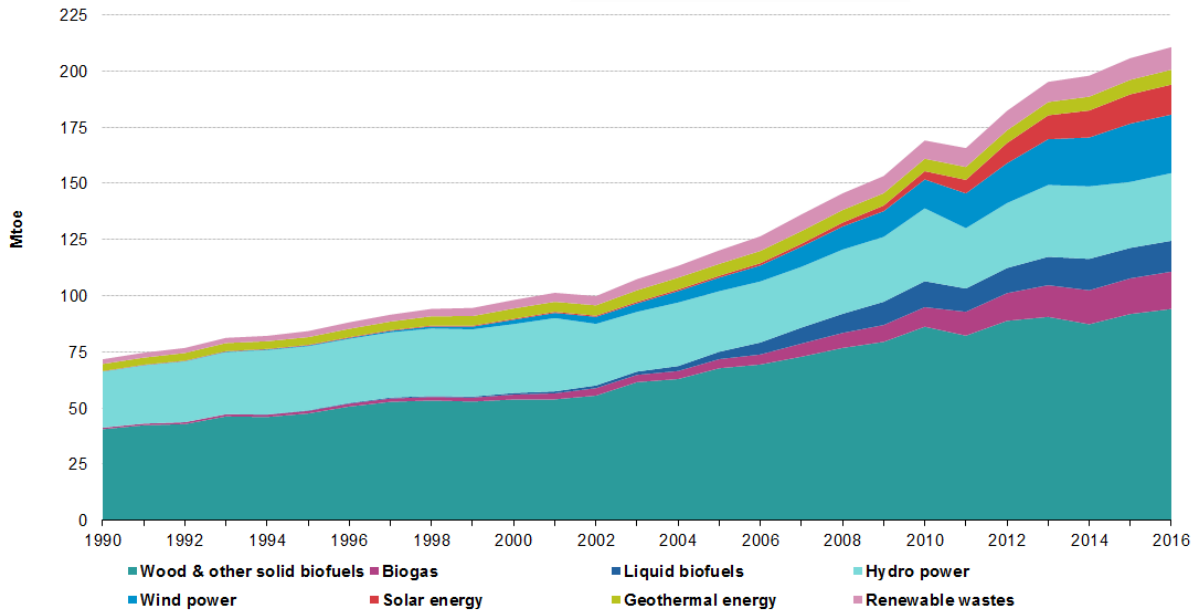


Fig 1: consumption of energy from renewable sources, EU-28, 1990-2016. Source: Eurostat

When planning an investment in renewable sources, its real costs should be taken into account. They are often not obvious and difficult to estimate. Those include:

- **Creation of the installation**
  - costs of construction, land purchase and obtaining the necessary permits
- **Service and maintenance**
  - costs of maintaining the installation in full working order, employee wages, training, security, insurance costs

- **Environmental impact**
  - project costs, possible compensations for the population and / or local authorities (e.g. compensation for noise, disturbance of animal migration)
- **Social costs**
  - the impact of the installation on local tourism and difficult to estimate social costs of relocation of the population
- **Durability**
  - costs related to the depreciation of the value of the installation and the necessary replacement of worn out elements
- **Recycling**
  - costs of dismantling of the installation and restoring the area to its pre-existing conditions

Wind energy

Wind farms have a distributed structure. They consist of individual wind turbines that can operate independently of the others and technically is a wind farm in itself. The common part is only the power distribution plant. The individual turbines are built of relatively cheap and available materials such as steel, aluminium, fiberglass, concrete or copper. The distributed structure of the power plant requires the production of a large number of turbines, which can generate a high cost per megawatt. On the other hand, it enables the almost in-line production of components, which reduces costs and facilitates the logistics of component transport.

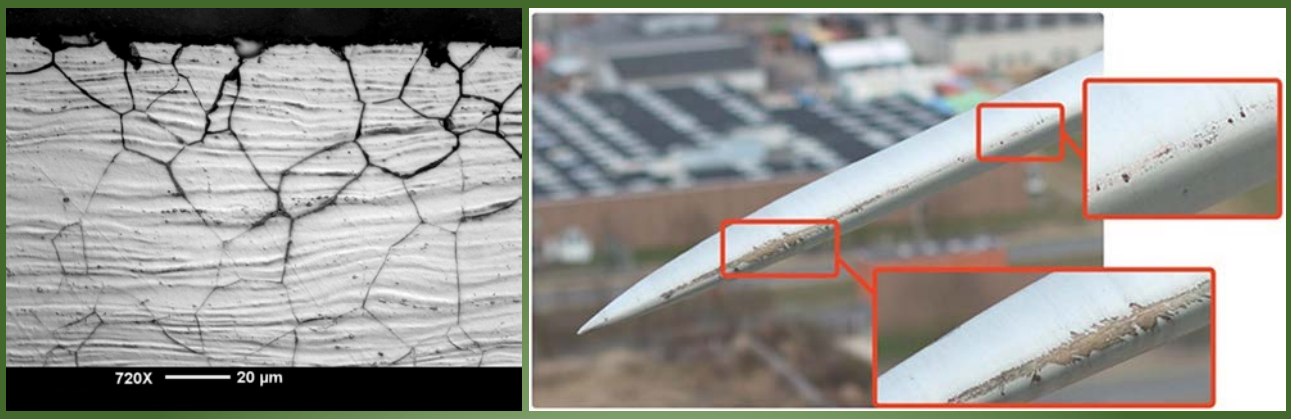
Fig 2: Wind farm, Copenhagen

A large number of turbines within a wind farm unfortunately means that their maintenance and repairs are expensive and time consuming. The specificity of the turbine structure (localization of most of the infrastructure at the top of the mast) forces conservators to work at high altitudes. Wind farms are responsible for the highest number of fatal accidents among power plant employees per megawatt hour generated.

Wind farms are characterized by relatively low durability. A running turbine generates strong vibrations which shorten the lifespan of individual components such as bearings. In addition, turbines are exposed to adverse weather conditions and often operate in environments with high salinity (marine and coastal installations).

DURABILITY OF WIND TURBINES

An operating wind turbine is exposed to a number of agents that shorten its lifespan. Companies designing wind farms have created their products so that they can work as long as possible without the need to replace elements. Practice has shown, however, that the influence of certain factors was sometimes underestimated in the designs.



Left: A salty working environment and significant changes in temperature lead to the formation of an intergranular collision in the aluminum from which some load-bearing elements of the turbine structure are made.
Right: Blade tips of a running turbine can accelerate to speeds exceeding 300 km/h. The collision of the blades with ice and salt microcrystals lead to erosion of the blade's leading edge. This significantly increases the aerodynamic drag and thus reduces the overall efficiency of the turbine.

Another consequence of the dispersed structure of wind farms is their high demand for space. This means high land purchase / lease costs and a significant impact on the surrounding landscape. In the case of Central Europe, projects to build wind farms in the Baltic Sea along the coast have met with strong protests from the tourism community. The inhabitants of coastal towns were concerned that the sight of windmills from coastal beaches would reduce their attractiveness and reduce the number of tourists visiting. However, further research has shown that the above correlation is not statistically significant.

The materials from which the wind turbines are made can be easily processed or disposed of. The dispersed structure also facilitates the process of turbine recycling. Moreover, after the removal of the turbines, the site is largely restored to its pre-construction condition.

SOLAR ENERGY

The use of a direct solar energy is based primarily on photovoltaic technology. It makes use of semiconductor structures (crystalline silicon) doped with rare earth metals. This results in high production costs of photovoltaic cells and the necessity to obtain expensive and rare materials. An additional risk factor is the effective monopoly of the People's Republic of China on the rare earth metals market, accounting for nearly 95% of the world production.

The operation and maintenance of a solar power plant mainly includes cleaning the cells from dust, as well as snow in colder climates. The costs strongly depend on the location. Frequent rainfall reduces costs but at the same time negatively affects the efficiency of the plant. In arid climates with a large number of sunny days in a year, deserts or semi-desert areas are often found. Photovoltaic farms located in such areas have high mean efficiency, but at the same time the costs of removing sand and dust from the cells may have a very negative impact on the profitability of the entire installation.

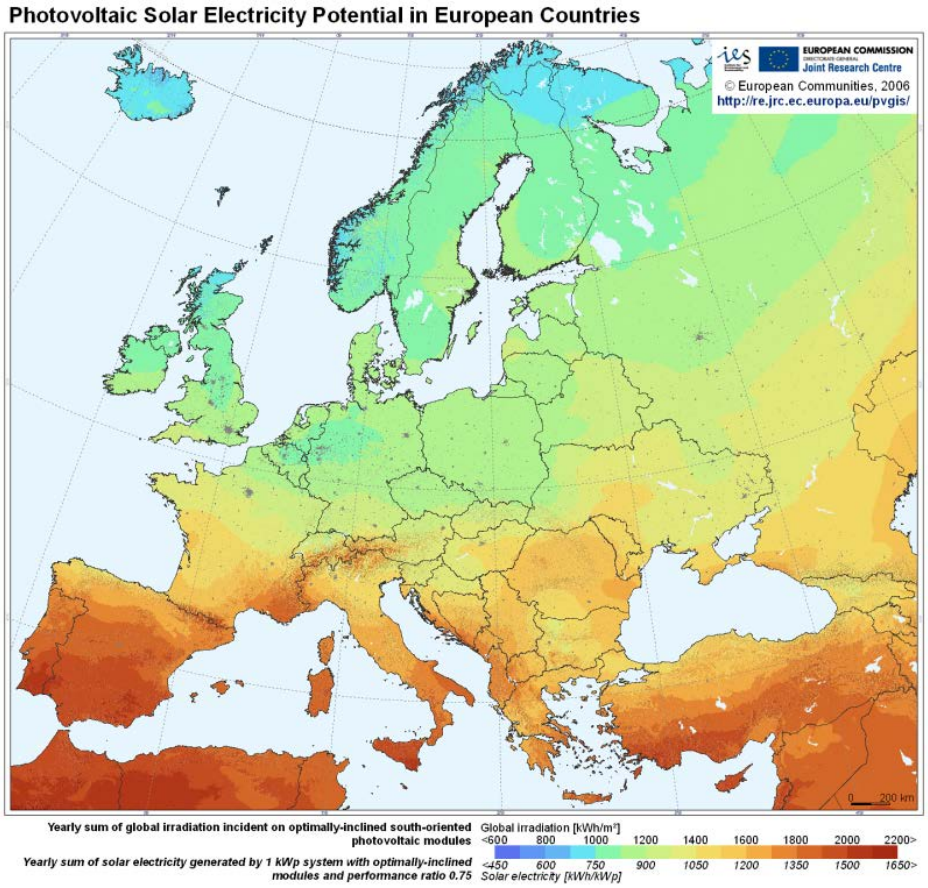


Fig 3: The potential of photovoltaic power plants in Europe

Solar power plants require quite a lot of space but much less than wind farms (per megawatt). However, the area occupied by the power plant is sufficient to clearly affect the

local albedo coefficient (ratio of power of the reflected radiation to the radiation reaching the surface).

Recycling of photovoltaic cells is a difficult and costly process, but it enables the recovery and then reuse of valuable rare earth metals. (Silicon is one of the main components of the earth's crust, and therefore its recovery is not economically justified).

Solar collectors, an alternative to photovoltaic cells, are based on a system of mirrors directing solar radiation to a central tank filled with a liquid (usually a funnel) for storing thermal energy. The conversion of thermal energy into electricity is done with the help of steam turbines, just like in conventional power plants.

Fig 4: Solar Power Plant - Collectors, California

Such power plants require non-diffused sunlight to operate, and their efficiency drops drastically even when a very thin cloud cover is present. For this reason, this solution is not used in temperate climates, where the number of completely cloudless days per year is small.

Hydropower

Hydroelectric power plants generate electricity by converting the potential energy of water into kinetic energy (driving turbines) by displacing the water vertically. The amount of available energy is proportional to the amount of water flowing and the change in elevation. The difference in the height of the water table is obtained by building dams that allow for the accumulation of flowing water. Hydropower plants are the most widely used source of renewable energy, accounting for around 16% of total electricity production in the world. The largest hydropower plants have power output in excess of 20 GW.

Fig 5: Three Gorges Dam, China - capacity: 22.5 GW

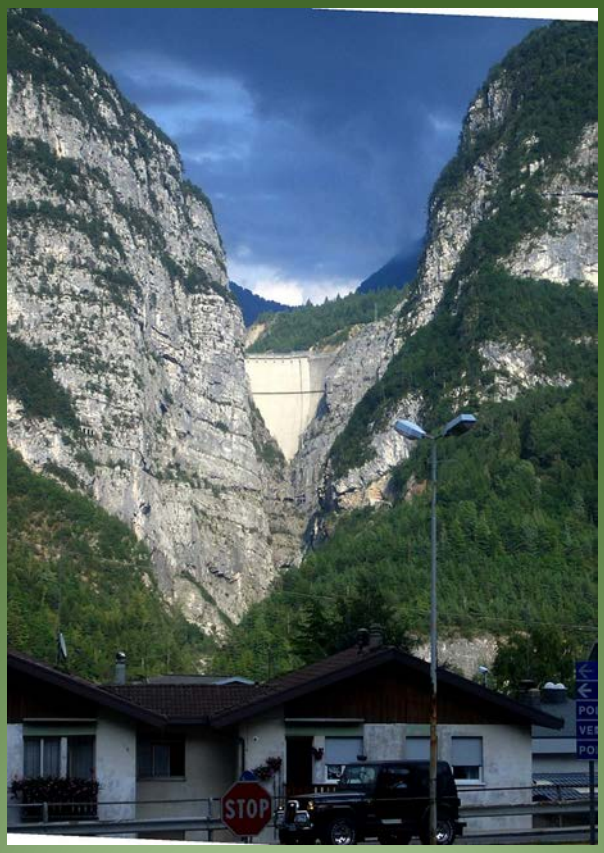
The construction of a hydropower plant requires the use of large amounts of materials, in particular concrete and iron. The technology of pouring concrete in the construction of the dam differs significantly from that used in the load-bearing structures of buildings. The concrete setting reaction is highly exothermic (it generates heat) and requires the use of an additional cooling system for concrete large volumes. This means that despite the use of cheap and readily available materials, the dam construction process is slow and costly.

Obtaining a significant difference of water levels often imposes the necessity to flood large areas above the dam. It generates high financial, social and environmental costs. On the other hand, the finished installation is very durable and requires relatively low maintenance in relation to the amount of electricity generated. In addition, the dam simultaneously performs a regulatory function on its mother river and may be used to stop or reduce the height of a flood wave.

One of the arguments against the construction of hydropower plants is the danger of a dam collapse or water overflowing through its top, for example as a result of landslides or severe earthquakes.

THE VAJONT RIVER DAM

The largest dam catastrophe in history occurred on October 9, 1963 in Italy. As a result of the mountain slope sliding into the reservoir above the dam, a wave exceeding 70 m in height was created, which overflowed the top of the dam and then flooded the town of Longarone below killing 1,917 people. Interestingly, the dam itself was not significantly damaged.



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WIND ENERGY - FOR AND AGAINST

The biggest challenge facing wind power is solving the problem of energy storage. Wind speed is a fast-changing parameter, and thus the power generated by a wind farm can also change quickly and significantly over time. This leads to problems with connecting wind farms to national energy networks.

KINETIC ENERGY AND WIND SPEED

The amount of kinetic energy carried by the wind that we can collect per unit time (i.e. the available power) strongly depends on the wind speed.

The available power P is the amount of kinetic energy carried by the air flowing around the turbine blades:

$$P = \frac{E_k}{t} = \frac{m(v)\,v^2}{2t}.$$

Note that the flowing mass m also depends on the speed:

$$m(v) = \rho \mathrm{V} = \rho S v t,$$

where S is the effective cross-sectional area of the turbine and ρ is the density of air.

After substituting, we obtain:

$$P = \frac{\rho S\, v^3}{2},$$

So the available wind power depends on the third power of speed, i.e. a 3-fold decrease in wind speed results in 27-fold decrease in power!

What to do when, in times of high electricity demand, the wind suddenly weakens?

One solution, especially popular in Germany, is the pairing of wind farms with gas turbines. An important feature of natural gas power plants is that they can be turned on and off very quickly. This allows for quick replenishment of energy shortages from conventional sources. However, it should be noted that burning natural gas emits significant amounts of carbon dioxide into the atmosphere, which stands contrary to the idea of renewable energy sources.

It is also possible to use chemical batteries or capacitors. Unfortunately, currently available technologies are characterized by a very unfavorable ratio of price to the amount of stored energy.

The best solution to the problem of storing energy from wind seems to be the construction of pumped storage installations. These installations resemble classic hydroelectric power plants, but they allow for conversion of electricity into potential water energy by pumping water from the lower to the upper reservoir during the period of production surplus over electricity demand. The combination of such an installation with a wind farm (and in the optimal case also with a solar power plant) allows for the storage of temporary surpluses of energy while ensuring the continuity of electricity supply to the national grid. Despite the high production costs of such hybrid installations, they now seem to be the future of renewable energy, and many European countries are announcing similar projects.

Fig 6: Pumped storage power plant in Żarnowiec, Poland

Does the average amount of wind change significantly across the country?

Wind speed depends not only on the pressure gradient, which forces the air to move, but also on the friction against the earth's surface. Terrain obstacles such as mountains, valleys, trees, buildings slow down the wind. Air particles colliding with obstacles (and even, to a lesser extent, with a flat ground surface) lose some of their kinetic energy. For this reason, a decrease in wind speed is observed close to the earth's surface. Often, at 100 m above ground level, the wind blows twice as fast as at the surface. This is why it pays off to build tall wind turbines that can utilize energy from faster-moving particles at higher altitudes. Moreover, the absence of terrain obstructions above the seas and oceans means that observed wind speeds in these regions are much greater than over land. In the case of Europe, the most favourable wind conditions are often found on islands, near the coasts and in flat and lightly forested plains.

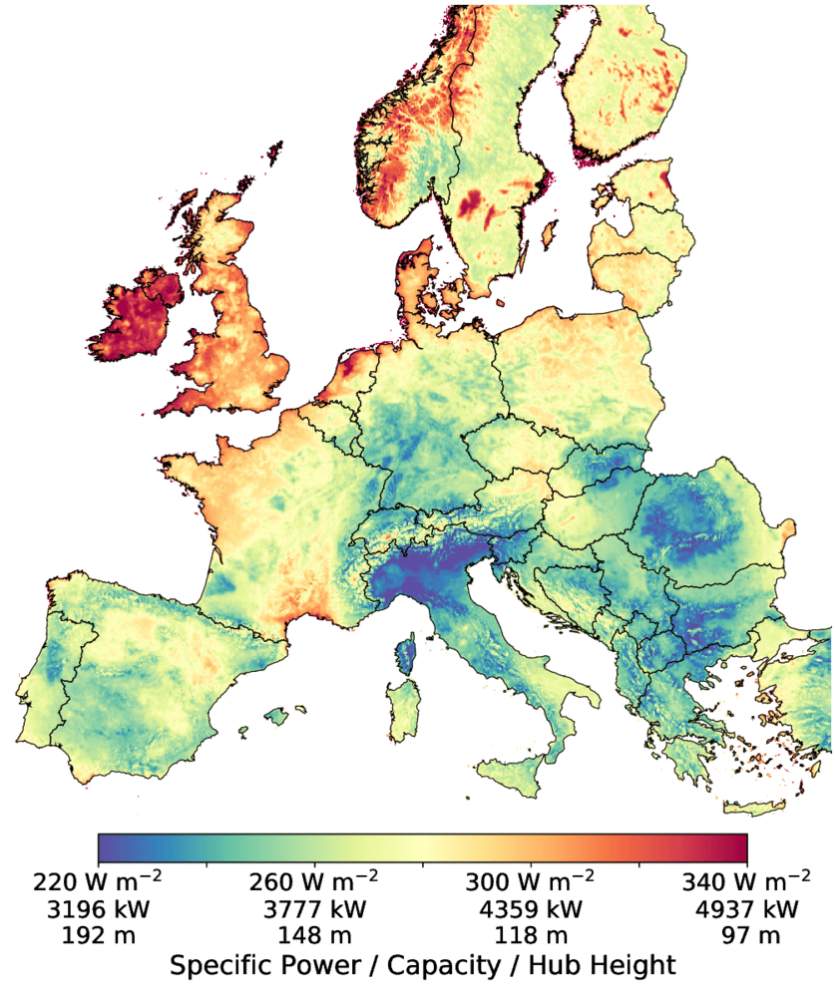

Fig 7: Available wind power over Europe

How does a working wind turbine affect its immediate surroundings?

Under optimal conditions, a wind turbine can extract half of the kinetic energy from the air flowing through it. This results in a significant drop in wind speed behind the turbine, known as the wind shadow effect. When designing a wind farm, this effect is taken into account, and individual turbines are placed far enough apart to minimize the negative effects of their interaction. Unfortunately, in the case of the largest wind farms, the problem is difficult to solve and the wind shadow can stretch for many kilometres on the leeward side of the power plant.

The second direct effect of the power plant's operation is the introduction of vibrations (turbulence) into the atmosphere. A sudden increase in turbulence can, under favourable circumstances, lead to the formation of clouds and even to precipitation. There is a known phenomenon of increased amount of precipitation in the immediate vicinity of the wind farm and the formation of rain shadows further downwind.

Fig 8: Turbulent cloud generation

Preparation for the debate

After reading the materials presented, you can proceed to directly prepare the arguments for the debate. Below are a number of questions. Answers to them can be good arguments for discussion. Some of them strongly support the thesis, others will help in refuting it. Some arguments are debatable and can be used by both sides.

Task.

Answer the following questions. Write answers that are also arguments for discussion in the appropriate place in the table (Worksheet No. 1).

Question card 1	Question card 2
What are the real climate costs of a wind farm?	*Is there enough kinetic energy in the Earth's atmosphere to meet the needs of humanity?*
Question card 3	**Question card 4**
Should aesthetic considerations, related to a significant change in the landscape, be taken into account when designing wind farms?	*Is placing windmills on bodies of water a better solution than on land?*
Question card 5	**Question card 6**
Is it justifiable to use renewable energy as a substitute for readily available fossil fuels?	*What are the possibilities of storing energy from wind farms? Do they make economic sense?*
Question card 7	**Question card 8**
Is the use of wind energy cost-competitive renewable energy? What could better alternatives be?	*Can the introduced turbulence affect the local cloudiness and thus the local albedo coefficient?*
Question card 9	**Question card 10**
Can wind energy be the primary source of energy in the power grid on a national scale?	*Does the sound produced by wind farms have a significant impact on the environment and the quality of life of the local population?*
Question card 11	**Question card 12**
Is wind energy efficient in terms of using space?	*What is the possible impact of windmills on local precipitation patterns?*
Your own question	**Your own question**

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Division into PROPOSITION and OPPOSITION teams

Task.

You already have arguments that you can use during the discussion. At this stage, you will prepare yourself directly to formulate the argument in accordance with the assigned role and to justify and defend them. Try to predict which rebuttals the other team will use and prepare your answers to rebuttals. In order to do this, use worksheet No. 2.

Wind energy–should we invest more?

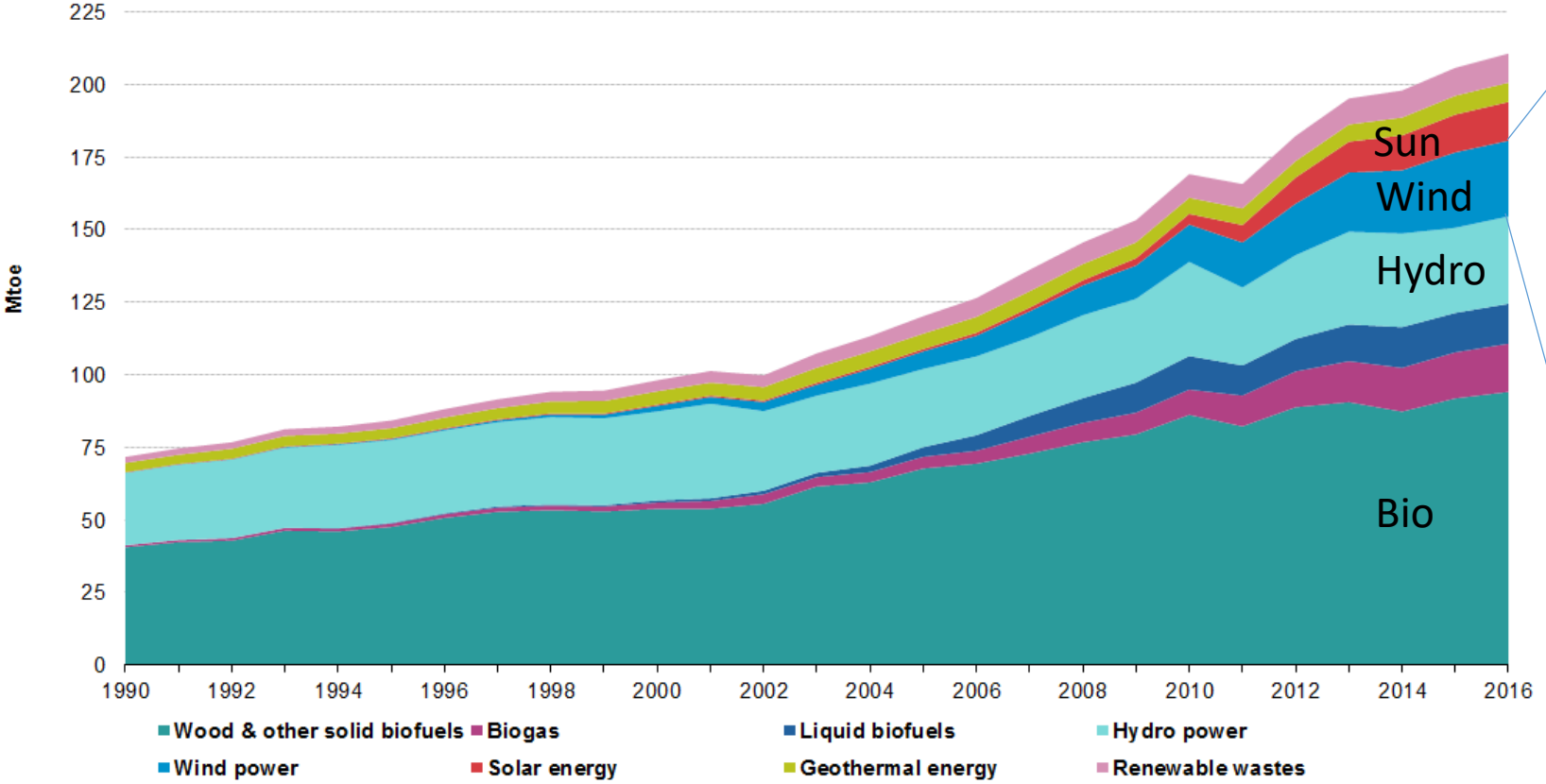


Fig 1: Energy consumption from renewable energy sources, EU-28, 1990-2016. Source: Eurostat

Renawable sources – real costs

- Creation and installation
- Maintenance
- Environmental influence
- Social impact
- Lifespan
- Recycling

Renewable sources - real costs

- **Wind energy**
  - **cheap and abundant materials – steel, aluminium, glass fibre, copper**
  - **costly, dangerous and time-consuming maintenance**
  - **short lifespan**
  - **large requirement for space per 1MW**
  - **relatively easy recycling**

Fig 2: Wind farm, Copenhagen

Renewable sources - real costs

- Solar energy
  - Photovoltaics
    - expensive and scarce materials – rare-earth elements
    - relatively expensive maintenance
    - moderate space requirements
    - influence on local albedo
    - expensive recycling
  - How about solar collectors?
    - vary low efficiency in diffused light conditions (thin clouds and aerosols)

Fig 3: Solar thermal collector power plant, California

Renewable sources - real costs

- Hydropower
  - large installations – cheap materials
  - significant social and environmental influence
  - relatively cheap maintenance
  - very long lifespan
  - high and difficult to estimate recycling costs

Fig 4: Three Gorges Dam, China

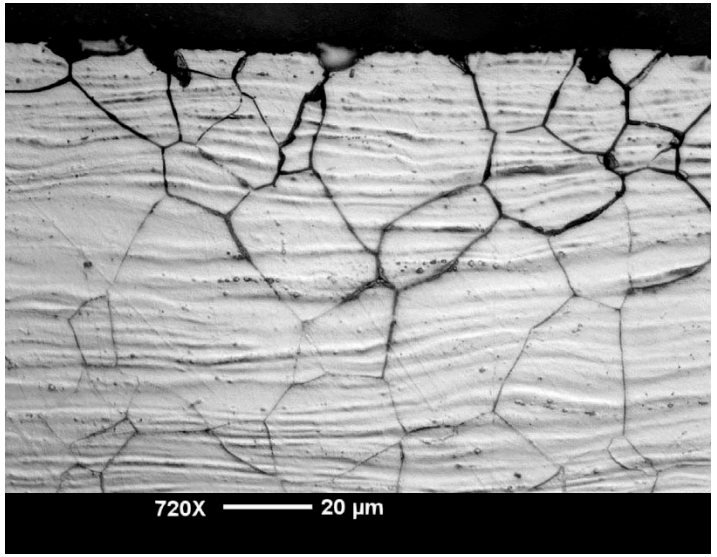
Wind energy – pros and cons

- **How much kinetic Energy is stored in the atmosphere?**
  - $P = \frac{E_k}{t} = \frac{m(t)\,v^2}{2t}$ $\qquad m(t) = \rho V = \rho S v t$ $\qquad P = \frac{\rho S\,v^3}{2}$

- **The amount of commercially available wind power exceeds the current needs of humanity twentyfold**

Wind energy – pros and cons

- Lifespan
  - wing erosion
  - salty working conditions - aluminium inter-granular corrosion



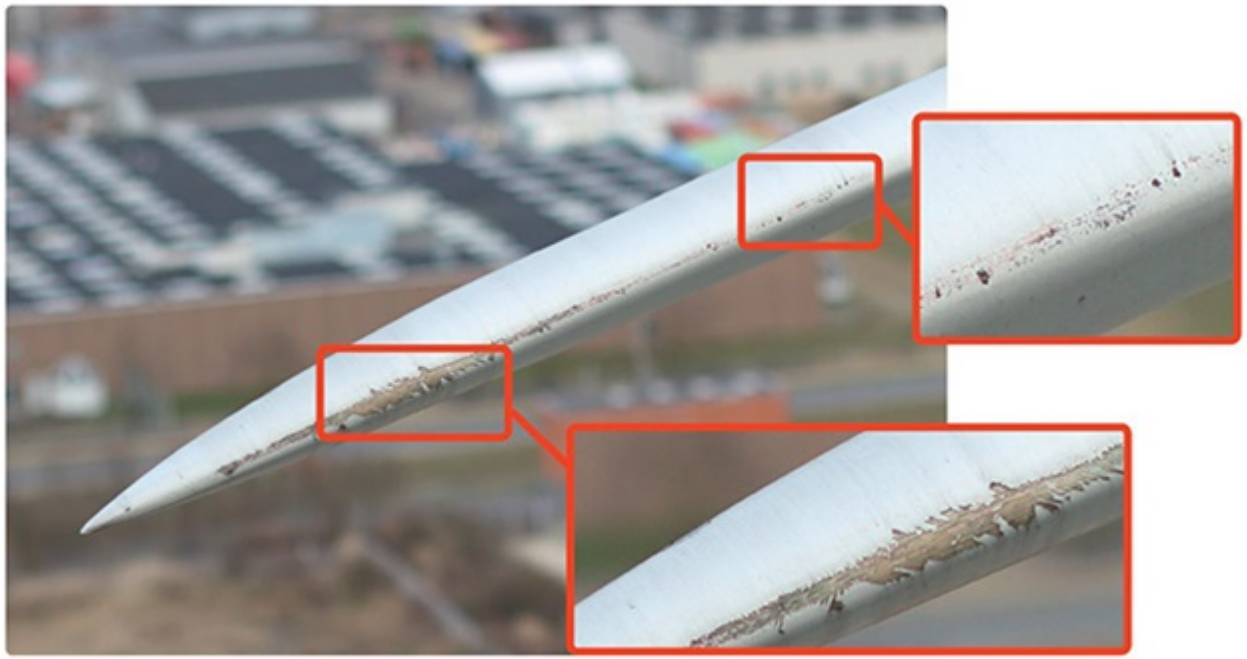


Fig 5: Wing erosion – top
aluminium inter-granular corrosion – left

Wind energy – pros and cons

- **Energy storage**
  - **difficulties in near-real-time wind speed forecasting**
  - **chemical Energy accumulators**
  - **supercondensators**
  - **pumped hydro storage**

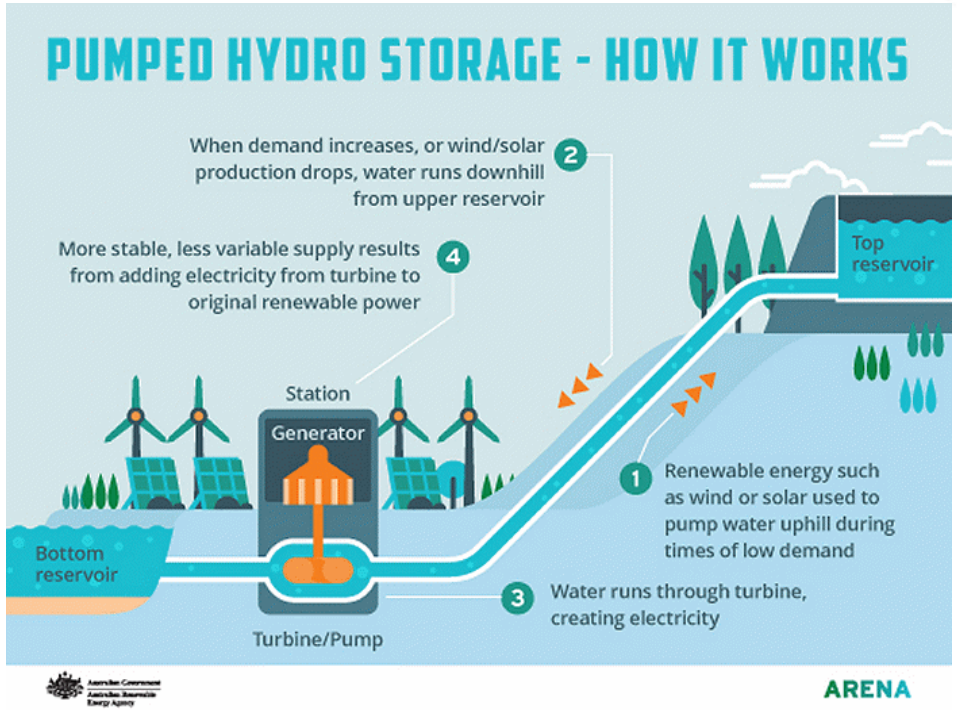


Fig 6: Pumped hydro storage

Wind energy – pros and cons

- **Influence on local precipitation pattern**
  - **rotating wind turbine – turbulence**
  - **cloud formation –**
    100% of relative humidity is not enough
  - **precipitation shadow**
  - **planetary albedo**

Fig 7: Turbulence based cloud generation

What about nuclear?

- Safety
- Real costs
- Waste
- Proliferation of nuclear weapons
- New technologies

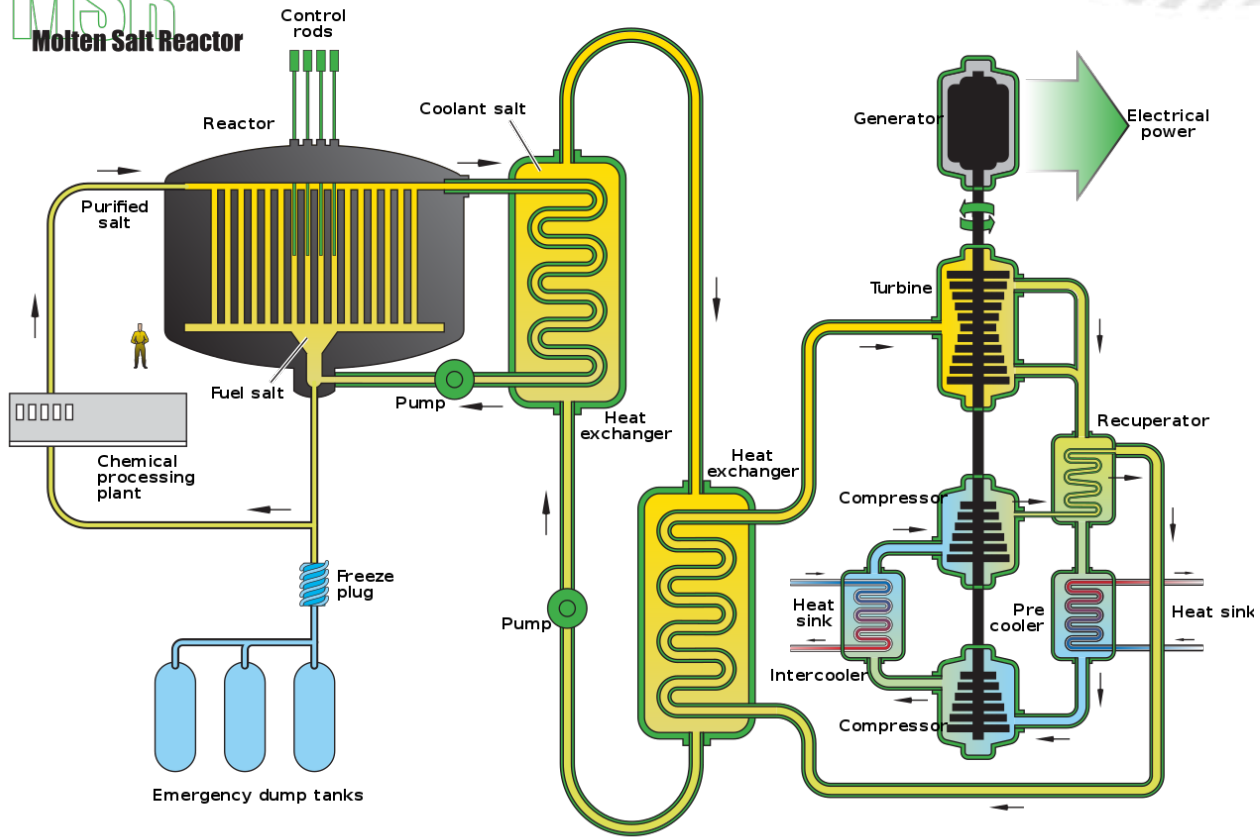


Fig 7: A schematic of a MSR type nuclear installation that utilizes liquid fuel design

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„Wind energy”

Material for teachers

With methodological guidelines, a lesson plan and an answer key to worksheets

The educational package "Wind energy" was developed within "Oxford debates for the education of young people in the field of mathematics and science" project.
It is a key material, facilitating the achievement of primary project goals, including increasing reasoning skills and interest in STEM, which in the future may result in taking up a scientific career.
When preparing students for the debate, one should not neglect the development of such skills as: communication excellence, argumentation or public speaking. Students should improve their ability to persuade effectively, argue properly, reason accordingly and speak out correctly. Composition of texts, using rhetorical means in oral statements, speaking in accordance with the rules of language culture, text interpretation, public speaking and presentation of texts, discussions and negotiations are of equally high importance.
In order to achieve the abovementioned goals, the implementation of thematic educational packages should be preceded by classes dedicated to preparation for debating as such. This can be accomplished in consultation with teachers of other subjects and the class teacher. The development of basic communication skills can be included in the class teacher's work plan, and the prepared lesson plans can be used during regular classes. Auxiliary materials can be found in the following documents:

1. **Warm up practice** – Annex No 2 to National frameworks for implementation of Oxford debates in STEM in school practice (pages 37-39);
   This document includes the following exercises: active listening, public speaking and debating skills.

2. **Lesson plans aimed at general development of debating skills** – Annex No 2 do National frameworks for implementation of Oxford debates in STEM in school practice (pages 40-55).

   This material consists of 7 lesson plans prepared by Dr. Foteini Englezou, president of the Hellenic Institute for Rhetorical and Communication Research. Scenarios are a guide to work. It is not necessary to follow all the lessons. The teacher can decide which scenarios (or their selected fragments) are most useful for working with a specific group of students. The document offers the following lesson plans:

   1. Communication skills
   2. Express your scientific argument, not your opinion
   3. Build a valid scientific argument
   4. Searching for evidence
   5. Enhancing students’ linguistic skills
   6. Rebuttal and refutation
   7. Fallacies

3. Methodological Guide for Teachers. ODYSSEY: Oxford Debates for Youths in Science Education

The final stage of preparation for debates based on specific packages is to familiarize students with the principles of debating, described in detail in the abovementioned document.

Wind energy

The "Wind energy" educational package consists of the following elements:
• Multimedia presentation;
• Video based on the presentation - https://youtu.be/IY-We5NlZOk;
• Educational package "Wind energy" - material for students;
• Worksheets (the same for all packages);
• "Wind energy" - material for the teachers (with answer key).
It is recommended to implement the package during a minimum of three lesson units.

The "Wind Energy" package is intended for additional classes in science and geography lessons both in primary school, as well as in secondary school and technical college. The package has been prepared to minimize the time needed to search for and select source materials. Students will receive ready-made materials in the form of source texts, tables, charts and auxiliary questions. On their basis, they develop arguments that can be used in the debate both to support the main resolution and to negate it.

Lesson 1. Wind energy among other energy sources

The first lesson aims to introduce renewable and non-renewable energy sources. Ideally, students should already know the basics of energy generation and electricity production, and be able to list the advantages and disadvantages of using different energy sources. If the knowledge from previous lessons cannot be used, it is worth recommending students to familiarize themselves with this topic in advance. During the lesson, the teacher can use a multimedia presentation or a film with the expert (multimedia presentation discussed by its author) and an educational package in which students will find information and inspiration that will allow them to formulate arguments for the debate in the future. The package is prepared in such a way that it is possible to easily prepare both arguments for and against the resolution.

Lesson 2. „Wind power plants are the best renewable energy source in mid-latitudes" – constructing arguments for and against the resolution

The aim of the second lesson is to formulate as many arguments as possible (both for and against the resolution) that will be used by students during the debate.

Lesson plan

1. Organizational issues, checking the attendance list, familiarizing with the topic and objectives of the lesson [5 minutes].
2. Preparation of arguments [25 minutes]

The teacher divides the class into teams of two. Each team receives 12 **question cards** available in the educational package (material for students – page 15) and 2 copies of worksheet No. 1 (one for each student individually). Based on the questions, students formulate arguments for the presented resolution, against the resolution and those that are debatable and can be used in the discussion by both teams. Students work together, but each student individually completes his/her worksheet. There are examples of selected arguments for worksheet 1 presented in the answer key in this material.

3. Teams: proposition and opposition are formed [10 minutes].

Team selection may be executed in many ways, each of them having both advantages and disadvantages.

- Students declare which arguments are closer to their beliefs. The teacher divides the class into teams (each with a similar number of students) in the manner reflecting their convictions.
- The second method assumes a division similar to the one above, with the difference that ultimately the team consisting of the supporters of a given resolution becomes the "opposition" team, while the opponents of the thesis become “proposition” team. The supporters of such a division assume that it teaches the participants of the debate to a greater extent to use arguments supported by facts, and is less based on emotions.
- Alternatively, division into teams can also be done randomly.
- Finally, team selection can also be made by the teacher in a subjective way, ensuring that each team has both leaders and students who require more help, so that both teams have similar “winning potential”. In order to save time for division, the teacher can do it at the beginning of the lesson, for example by distributing worksheets printed on sheets of different colours or marked in some other manner.

The teacher distributes worksheets number 2 to the students (one for each student) and explains the homework. An example of a filled out worksheet is available in the answer key in this document.

Students in each team read prepared arguments in accordance with the assignment to a given group. Each student receives 1 argument, which he/she will develop (as homework) according to the guidelines in worksheet No. 2.

Each team also appoints 3 people who will present the arguments prepared by the entire group. Students decide the order of their speeches. During the debate, other team members who are not directly involved in the debate, fill out worksheet No. 3

4. Summary of the lesson, evaluation of students' work [5 minutes].

Lesson 3. Debate

During the final lesson, the teams conduct a debate according to the guidelines contained in the "Methodological Guide ..." It takes 45 minutes in total to conduct a full debate. During the debate, the teacher does not comment on the arguments or indicate the fallacies made by the students on an ongoing basis.

An exercise-based debate should be structured as follows:

1. Opening of the debate by the moderator/chairperson [3 minutes].
2. Initial vote by the audience [2 minutes].
3. 1st Researcher-Debater of the A research-team: Constructive Speech [4 minutes].
4. 1st Researcher-Debater of the B research-team: Constructive Speech [4 minutes].
5. Cross-fire between the researchers-debaters (1) of both research teams [3 minutes].
6. 2nd Researcher-Debater of the A research-team: Rebuttal Speech [4 minutes].
7. 2nd Researcher-Debater of the B research-team: Rebuttal Speech [4 minutes]
8. Cross-fire between the researchers-debaters (2) of both research teams [3 minutes].
9. Preparation time for the Summary and Final Rebuttal by both research teams [2 minutes].
10. 3rd Researcher-Debater of the A research-team: Summary Rebuttal [2 minutes].
11. 3rd Researcher-Debater of the B research-team: Summary Rebuttal [2 minutes].
12. Grand Cross-fire between the researchers-debaters (1 & 2) of both research-teams [3 minutes].
13. 3rd Researcher-Debater of the A research-team: Final Focus Rebuttal [2 minutes].
14. 3rd Researcher-Debater of the B research-team: Final Focus Rebuttal [2 minutes].
15. Final vote by the audience / Short written feedback [3 minutes].
16. Presentation of the results by the moderator [2 minutes].

If the debate takes place during extra-curricular activities, then it is recommended to devote, for example, 90 minutes for this part. This will allow you to prepare the room for the debate, recall the rules, conduct the debate and discuss its course and finally evaluate the work of students.

In terms of classroom conditions, it would be ideal to allocate two adjoining lesson units to the debate. Taking into account the school circumstances, organizational difficulties and the inability to devote too many lessons to content extending the core curriculum, the debate can be conducted in one lesson, while maintaining high discipline in time. In this case, it is recommended that during the next lesson with the class additional 10 minutes are spent discussing the debate, pointing to strengths and mistakes made by the participants of the debate.

In this format, 6 students (3 from each team) actively participate in the debate. The teacher may also appoint a moderator from among the students and a time keeper. The rest of the students will receive worksheet number 3. Their task will be to listen carefully to the debate and to note the opposing team's strengths and areas for improvement, and to justify their choice. Completed worksheet no. 3 may be the basis for issuing a grade for activity in the lesson for students who did not take part in the debate directly, but participated in its preparation and were active observers of its course.

Worksheet No 1 – answers

The table below contains examples of answers to question cards gathered in the worksheet No. 1. The answers may help to formulate arguments in the debate on the presented resolution.

FOR	„GREY AREA”	AGAINST
Question card 1. *What are the real climate costs of a wind farm?* An argument that is often raised by people sceptical towards renewable energy sources is the possible high energy or climate cost (emission of pollutants) of the construction of renewable installations. Wind energy is the best renewable energy source in this respect. Windmills are built from easily accessible materials (mainly steel, aluminium and copper). Their production is not associated with significant emission of pollutants into the atmosphere, and the installation itself can be relatively easily recycled. *Question card 2.* *Is there enough kinetic energy in the Earth's atmosphere to meet the needs of humanity?* While wind may appear to be ubiquitous on our planet, the amount of kinetic energy associated with the movement of air and the rate of its renewal is limited. Research shows that currently the amount of available and commercially viable wind energy (calculated on average per year) exceeds the demand of humanity even twenty-fold. However, it should be noticed that energy demand is growing rapidly with	*Question card 5.* *Is it justifiable to use renewable energy as a substitute for readily available fossil fuels?* Fossil fuels such as oil, natural gas and fossil coal are readily available and relatively cheap sources of energy. Burning these fuels, however, emits significant amounts of carbon dioxide into the atmosphere, which is one of the main greenhouse gases. Uncontrolled CO2 emissions can lead to an increase in the global temperature of our planet, which has hardly predictable and dangerous consequences, such as rising sea levels and changing / shifting climate zones. Recent research suggests that it is possible to recover hydrogen from fossil fuels while leaving carbon-carrying particles beneath the surface. The product of hydrogen combustion is pure water vapour. *Question card 6.* *What are the possibilities of storing energy from wind farms? Do they make economic sense?* One possible solution to the problem of high variability and unpredictability of wind speed is to store energy for later use. However, storing large amounts of energy is technically difficult and entails significant costs. Two	*Question card 9.* *Can wind energy be the primary source of energy in the power grid on a national scale?* Apart from solar energy, wind energy is the most easily available renewable energy source. Unfortunately, wind is one of the fastest changing atmospheric parameters, and its forecasting is very difficult. As a result, even covering a large part of the country with windmills could not guarantee continuous energy supplies for the population and industry. It is possible to store energy obtained from a wind farm, but it entails additional costs. *Question card 10.* *Does the sound produced by wind farms have a significant impact on the environment and the quality of life of the local population?* The operation of windmills is associated with the introduction of significant vibrations to the immediate environment. The frequency of these vibrations depends on the size of the fans and their rotational speed. In most cases, the vibrations, and hence the sounds produced by the

the rapid industrialization of less developed countries and automation in countries with more developed economies. Consequently, wind energy is a good proposition in the short and medium term, i.e. in the key period for preventing irreversible climate change.

Question card 3.

Should aesthetic considerations, related to a significant change in the landscape, be taken into account when designing wind farms?

Wind farms significantly influence the surrounding landscape. Currently operated structures often exceed 100 meters in height, and thus are visible from many kilometres. Many express the opinion that windmills have a negative impact on tourism, and thus have a negative impact on the local economy. However, the conducted sociological research showed no statistically significant decrease in the number of tourists visiting the areas where wind farms were located. Moreover, the researchers postulate that the presence of windmills contributes to the creation of a positive impression of the "ecological friendliness" of the surroundings among tourists.

Question card 4.

Is placing windmills on bodies of water a better solution than on land?

Wind power plants require a significant amount of space and are also directly dependent on the local distribution of wind directions and speed. Both of basic methods include the use of chemical cells (accumulators) or the use of the potential energy of water in a gravitational field (pumped storage plants). Chemical cells are very expensive in relation to the amount of energy stored, and also require hard to obtain and often toxic substances to produce them. This also leads to the relatively difficult recycling of the used cells. Fortunately, technological advances in the field of chemical batteries have been very fast in recent years, and therefore the use of large batteries for wind energy storage may become more viable in the coming years / decades. Using the potential energy of water is a better solution at the moment. However, it requires the construction / use of at least two water reservoirs with different surface elevations. The excess energy is used to pump water to a higher reservoir. This, in turn, is used to drive the turbines in times of wind shortage.

Question card 7.

Is the use of wind energy cost-competitive renewable energy? What could better alternatives be?

The cost of producing a single windmill is relatively low, and the necessary materials are cheap and generally accessible. A power plant, however, consists of a significant number of windmills that occupy a significant area (land costs). Due to their dispersed nature, wind farms generate relatively high maintenance costs. Moreover they require high altitude work that is a dangerous task. The number of accidents related to the operation is the highest for wind farms among all typical energy sources (per kWh produced). Since the construction of windmills is technically simple wind power plant, remain in the infrasound area, i.e. frequencies below the audible limit of the human ear. However, some animals, such as fish, are capable of picking up low-frequency sounds. It has been proven that offshore wind farms can scare off shoals of fish as well as affect spawning. More recent research suggests that the initial effect diminishes as the fish adapt to the new situation. To determine the long-term effects of windmills on the surrounding fauna, further research is needed and is currently being conducted.

Question card 11.

Is wind energy efficient in terms of using space?

A wind farm with significant power requires the use of a large number of windmills, often in excess of a hundred. The windmills must remain sufficiently separated due to their mutual interactions (mainly the effect of the wind shadow behind the windmill). The amount of space required for a wind farm is the largest of all renewable sources (per kWh). The cost of land purchase can represent a significant part of the construction of a power plant. Effective use of the space between the fans is difficult due to safety standards. It seems that wind farms can be a good solution for countries with large uninhabited areas (e.g. deserts, large bodies of water). For densely populated countries with no access to large bodies of water, other renewable sources such as

these factors make locating windmills over large bodies of water more beneficial than locating them on land. Shelf seas seem to be a particularly good choice due to the large amount of space available, while being able to build windmills directly on the seabed (the depth of the shelves rarely exceeds several dozen meters). Open water bodies are characterized by a more stable and thus predictable distribution of wind directions and speeds. This is due to the lack of objects that disturb the air movement, such as terrain elevations, trees or buildings. Moreover, for the same reason, the average wind speeds over seas/oceans are much higher than over land.	and does not require the use of advanced technologies and rare materials, it makes them a good, non-emission alternative to burning fossil fuels in developing countries with a low level of industrialization. However, in countries with access to a large amount of slow-flowing water, a better solution may be to build hydroelectric plants, which also do not require the use of advanced technologies, and are characterized by greater power and predictability compared to a wind installation at a similar price. *Question card 8.* *Can the introduced turbulence affect the local cloudiness and thus the local albedo coefficient?* Wind turbines generate a significant amount of vibrations during operation, which contributes to the formation of strong turbulence in the air masses that move in the immediate vicinity of the windmills. In high humidity conditions, the introduction of turbulence may lead to creation of cloud droplets. Formation of large sheets of low thin clouds downwind of the wind power plant has been observed. This can affect local weather patterns as well as the balance of radiative energy transfer (visible light, infrared) in the atmosphere. It is worth noting that clouds of this type induce a strong radiative cooling of the atmosphere, thus counteracting climate warming.	hydropower or solar photovoltaics may be a much better choice for economic reasons. *Question card 12.* *What is the possible impact of windmills on local precipitation patterns?* The turbulence generated by the blades of rotating windmills can, in high humidity conditions, lead to cloud formation in the wind farm's wind shadow. Under favourable conditions, precipitation (mainly rain) may occur immediately behind the power plant. This increases the amount of local rainfall (in the vicinity of the power plant) but also reduces the amount of water vapour available in the atmosphere. In areas with a single, predominant wind direction, this leads to a rain shadow on the leeward side of the power plant, where significantly reduced precipitation totals are observed. This can generate negative effects for local nature and agriculture.

Worksheet No 2 – examples of arguments

Argument with reasoning	Foreseen rebuttals of the other group	Answers to rebuttals
(Claim) It is reasonable to invest in wind energy, even though it does not guarantee continuity of energy supplies. (Warrant) It is possible to store energy from wind farms for later use. (Evidence) One possible solution to the problem of high variability and unpredictability of wind speed is to store energy for later use. The two basic methods are the use of chemical cells (accumulators) or the use of pumped storage power plants, where the excess energy is used to pump water into the elevated reservoir.	Chemical cells are very expensive in relation to the amount of energy stored, and also require hard to obtain and often toxic substances to produce them. They are also relatively difficult to recycle.	Technological progress in the field of chemical batteries is very fast, and therefore the use of large batteries for storing energy from wind should become more and more viable in the coming years.
		Due to the rapid development of the automotive industry based on electric drives, the amount of chemical cells that need to be recycled is constantly increasing. The effect of scale allows for a significant reduction in unit costs and stimulates the rapid development of new, more efficient recycling techniques.
	The technology of pumped storage power plants requires the construction / use of at least two water reservoirs with different water levels. This is often associated with high costs and a significant space requirement.	Pumped storage installations are very durable, which allows for the amortization of the initial construction costs over many decades of operation.
		It is possible to use the existing river dams. In such a case, it is necessary to stabilize the water level below the dam. One option is to build a small and inexpensive auxiliary dam (or weir) below the main dam. An example of such an installation is the Solina-Myczkowce Hydroelectric Power Plant in Poland.

<table>
<tr><th>Argument with reasoning</th><th>Predicted rebuttals of opposite team</th><th>Answers to rebuttals</th></tr>
<tr><td rowspan="4">(Claim)

Wind energy is ineffective due to excessive space requirements
(Warrant)
Other renewable energy sources generate more power per unit area occupied by the installation.

(Evidence)
A wind farm of significant power requires the use of a large number of windmills, often in excess of a hundred. These need to be sufficiently separated from one another due to their mutual interactions (mainly the effect of the wind shadow behind the windmill). The amount of space needed for a wind farm is the largest of all renewable sources (per kWh). The cost of land purchase can represent a significant part of the construction of a power plant.

(Impact)
Effective use of the space between the individual windmills is difficult due to safety standards.</td><td rowspan="2">Many countries have large uninhabited areas (e.g. forests, steppes, deserts, large bodies of water, shelf seas). Wind farms built in such areas do not require large investments in land purchase and have little impact on the quality of life of the human population.</td><td>Uninhabited areas are often refuges for wild nature. The construction of wind farms, and the related use of heavy machinery, can cause much greater environmental damage there than it would in the vicinity of human settlements.</td></tr>
<tr><td>Areas located far from human settlements are often characterized by unfavourable natural conditions for the construction of wind farms. For example, desert dust can drastically shorten the lifespan of bearings, and sea salt can lead to intergranular corrosion in aluminium elements of windmill structures.</td></tr>
<tr><td rowspan="2">It is possible to use the space between the individual windmills. Due to safety standards, people have limited access to the plant site. This makes it a great location for wildlife refuge.</td><td>The sounds produced by the wind farm remain mainly in the infrasound area, i.e. frequencies below the hearing limit for the human ear. However, some animals, such as fish, are capable of picking up low-frequency sounds. It has been proven that offshore wind farms can scare away shoals of fish as well as negatively affect spawning.</td></tr>
<tr><td>A rotating windmill poses a great threat to wild birds. Blade tips may rotate at speeds exceeding 300 km / h. This gives flying birds little time to avoid a collision, which in most cases ends up tragically for them.</td></tr>
</table>

Worksheet no. 1

The educational package contains a set of questions to help prepare arguments for discussion on the resolution. On their basis, prepare a set of arguments and group them into those that are clearly in favor of the resolution, against the thesis, and those arguments that can be used by both teams. Write them down in the appropriate parts of the table.

FOR	„GREY AREA”	AGAINST

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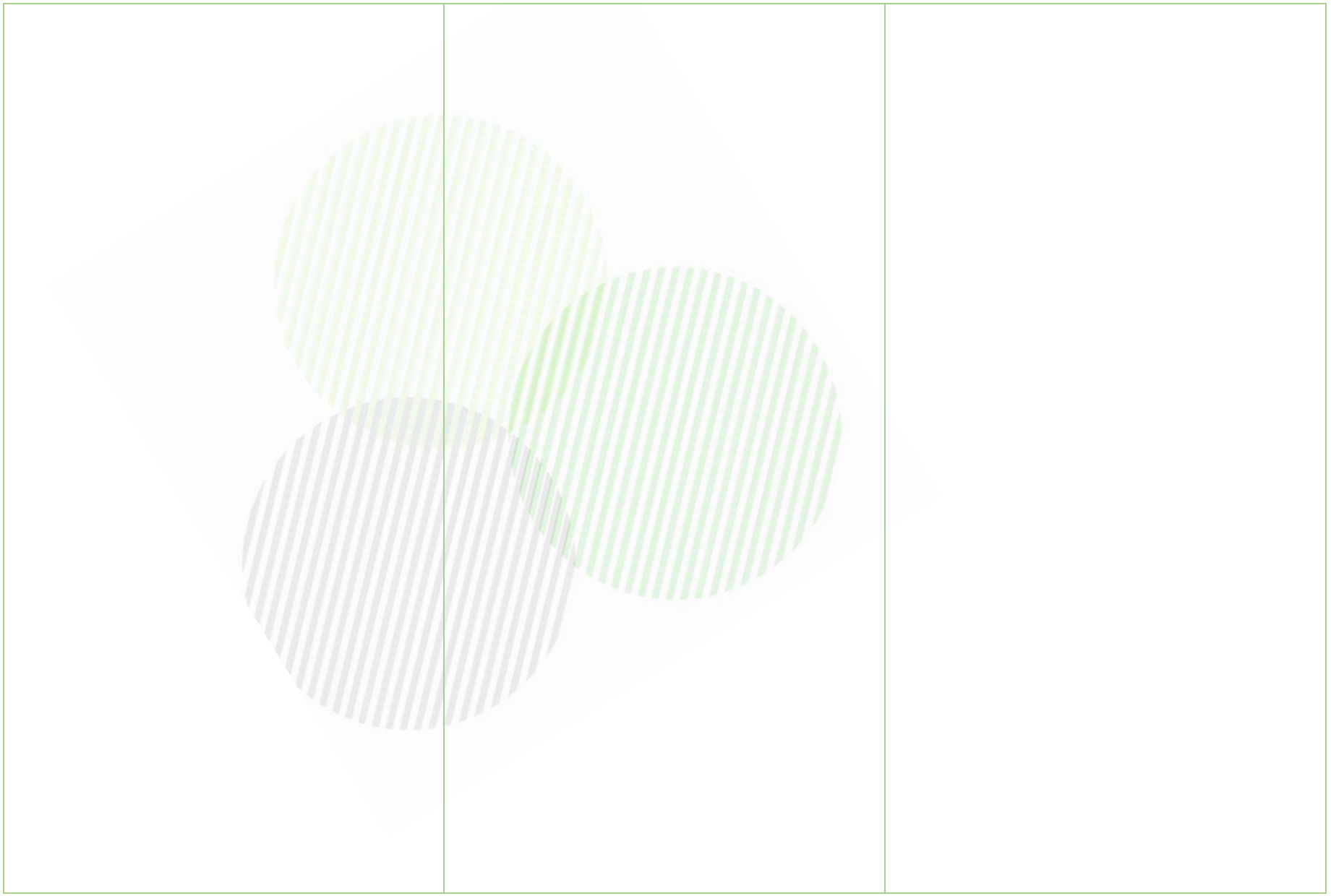

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Worksheet no. 2

Based on the materials provided by the teacher, prepare arguments for discussion. One group of students prepares arguments supporting the resolution, the other one - opposing arguments. Use the proposed template.

ARGUMENT 1.

Argument with reasoning	Foreseen rebuttals of the other group	Answers to rebuttals

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ARGUMENT 2.

Argument with reasoning	Foreseen rebuttals of the other group	Answers to rebuttals

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Worksheet no. 3

Name and surname:……. Class……. Team: proposition/opposition

During the debate, hear and observe carefully the speeches of the debates from the other team. Then, evaluate which speech convinced you the most and which areas of your opponents' speech should be improved.

1. In terms of **argumentation (**e.g. the quality of the arguments presented, credibility of the data and scientific evidence) in the rival team I was most convinced by the speaker No. .....

Reason:

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2. In terms of **the style of presentation and communication with the audience** (e.g. confident, persuasive, authentic and dynamic posture, moderate gestures, assertive voice variety, good eye contact with the audience, use of moderate humor, friendly and professional approach to all participants, effective use of body language) in the rival team I was most convinced by the speaker No. .....

Reason:

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Indicate the element of the rival team's performance that requires improvement. Justify your answer.

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Reason:

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