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CLIMATE CHANGE AND THE CULTIVATION OF ENERGY CROPS

Abstract
Atmospheric circulation, temperature, hydrological cycles, and solar radiation affect all organisms on earth. Rapid climate change, with positive and negative effects, forces people to create new and effective solutions in the fields of industry, agriculture and construction in all aspects of the global economy. Developing appropriate strategies for growing energy crops using organic methods will help to reduce the negative effects of global environmental change.

Key words
Climate, climate change, energy crops

Introduction

Climate change at the national and global levels is conducive to increasing the areas and the potential of use of energy crops to produce biomass, and for the introduction of species resistant to biotic and abiotic environmental changes into farming.

Bearing in mind the changes in climate, which are accelerating and often surprising with new phenomena, it is appropriate to move away from the definition of the climate to understand its structure, the influence of external factors and, consequently, the progressing changes. Climate is understood as a characteristic course of weather phenomena, which have been cyclical over many years [1]. Most often observations made over a period of thirty years are considered. The climate is determined by the course of the weather, including a wide variety of factors, such as temperature, precipitation, or wind. On Earth, we can distinguish three basic climate-forming processes: water, heat and air circulation. In addition, geographic factors play an important role, including the height above sea level and the layout of the lands and oceans. The life of organisms and the frequency of their occurrence are conditioned by ecological factors, including the climate.

Climate and environmental changes that have occurred in recent years are due to natural causes. One cannot forget, however, that man and his activities are also contributing significantly to the effects of extreme weather conditions. Over the last decades, researchers have observed that these changes are much larger and are occurring much more quickly because of increased intensity of anthropogenic activities that are unfavorable to the environment. In 1988, on December 6, Resolution 43/53 of the United Nations General Assembly was made, which recognized that climate changes and their negative effects are a common problem for humanity. At the same time, a special unit was also created, the Intergovernmental Panel on Climate Change (IPCC), which aims to investigate the causes and effects of climate change and to disseminate the information obtained to the authorities of different countries and individuals or institutions interested in this subject [2].

The causes and effects of climate changes

Factors that significantly affect climate change are divided into two main groups. Changes due to natural factors and those that result from human activity (anthropogenic effects). Multiple, unfavorable human activities include, but are not limited to, atmospheric pollution. This is due to excessive CO_2 emission during the combustion process of fossil fuels like coal, crude oil, or natural gas. The significantly increased level of CO_2 results in the retention of heat in the atmosphere and consequently results in global warming.

The dissemination of the opinion on the significant impact of CO_2 emissions on the greenhouse effect has begun activities aimed at extending the idea of protecting the Earth's climate. The most important document to influence the imposition of restrictions associated with CO_2 emissions is the Kyoto Protocol from 1998 [3]. It complements the United Nations Framework Convention and the international treaty on counteracting global warming. This document came into force on February 12, 2005. According to the provisions of the treaty, the countries that have ratified it have pledged to reduce their greenhouse gas emissions by at least 5% by 2012 compared to the 1990s. Any action taken on a large scale at that time did not bring the expected results. Many countries have not undertaken any commitments to cut CO_2 emissions or have merely decided not to increase it. The absence of any restrictions and sanctions has led to unsatisfactory results in the fight against adverse climate changes.

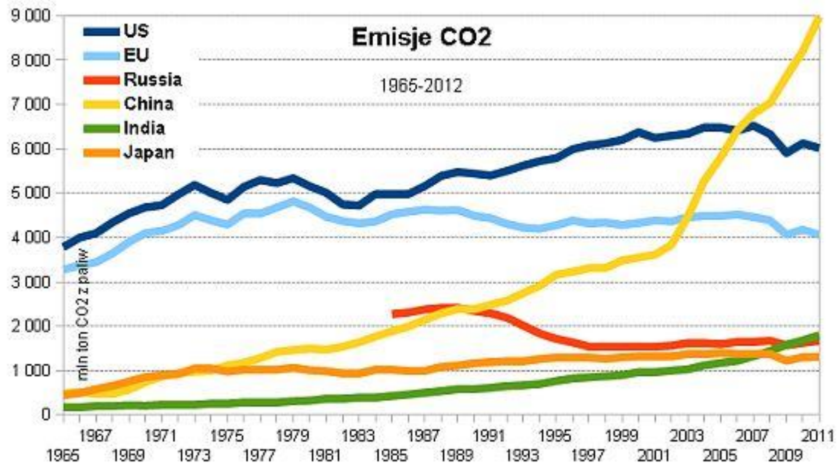


Fig. 1. The dynamics of CO_2 emission in 1965-2012
Source: [4]

Emisje CO2 – CO2 emissions;

The graph above shows that in the 1960s (initial state) almost 70% CO_2 was emitted by Western countries. As of today, this ratio has been significantly reduced. The United States, once responsible for nearly 35% of greenhouse gas emissions, reduced this to only 18%, while the EU countries cut emissions from 29% to 12%. Unfortunately, in the last dozen or so years, new leaders like China or India have increased CO_2 emissions due to rapid economic growth. Most emissions come from the combustion of coal (43%), oil (33%), gas (18%), cement production (5.3%) and gas extraction processes (0.6%). The total CO_2 emissions calculated from the beginning of the Industrial Revolution (approx. 1870) will reach 2,015 billion tons by the end of 2013, with 70% corresponding to the combustion of fossil fuels, and 30% to deforestation and other interferences in land surfaces [5]. Nearly 86% of CO_2 is produced by countries that are non-EU countries that are not covered by the "3x20" directive planned for 2020, and did not ratify the Kyoto protocol. These countries have strongly increasd coal mining and CO_2 emissions. The global use of coal will most likely increase more than twice by 2030. Today, the worldwide power industry is 41% based on coal. By 2030, the share of coal in energy production and its use in other industries is expected to rise to 44% [6].

Studies on the mechanisms and effects of climate change are being undertaken. The effects of the progressing climate changes include the melting of ice caps on the poles. At the North Pole, the area covered by arctic ice has decreased by 10%. The thickness of the ice under the surface of the water has decreased by about 40%. The ice cap in Antarctica has undergone similar processes [7]. According to the Japan Aerospace Exploration Agency (JAXA), the area of ice in the Arctic is getting smaller and smaller (Figure 2).

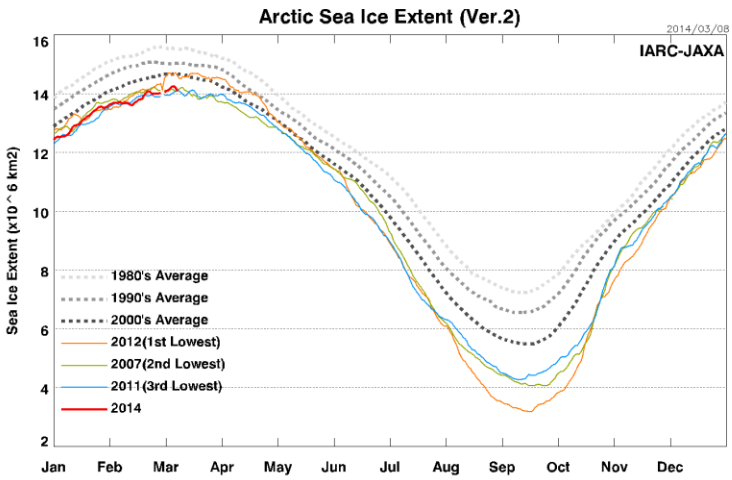


Fig. 2. The range of ice in the Arctic in 2014 against the background of recent years IARC-JAX A
Source: [8]

Another significant change is the shrinking of the glaciers. It is estimated that up to 75% of glaciers will disappear in the Swiss Alps by 2050. It is likely that melting of the glacier covering Kilimanjaro will occur even faster, as early as 2020. The Austrian and Swiss communities are trying to protect the glaciers on their own, covering them with special foils to protect them from being completely melted. Because of global warming, sea levels are rising. During the last century, the water level has risen by as much as 25 centimeters, and is expected to grow further to 88 centimeters by 2100. As a result, low-lying islands and coastal areas may be flooded. Areas located deeper inland may also be flooded by sea water, thus destroying crop areas and causing pollution of fresh water resources. Progressive climate change results in extreme weather conditions, such as hurricanes, floods, storms and droughts. In addition, compared to the previous decades (Fig. 3), the last decade is full of natural disasters, particularly floods and hurricanes. Increasing temperatures can cause significant shortages in access to drinking water, to which 1.1 billion people currently do not have permanent access. The rise of the temperature will increase the number of people suffering from water shortages by up to 3.4 billion.

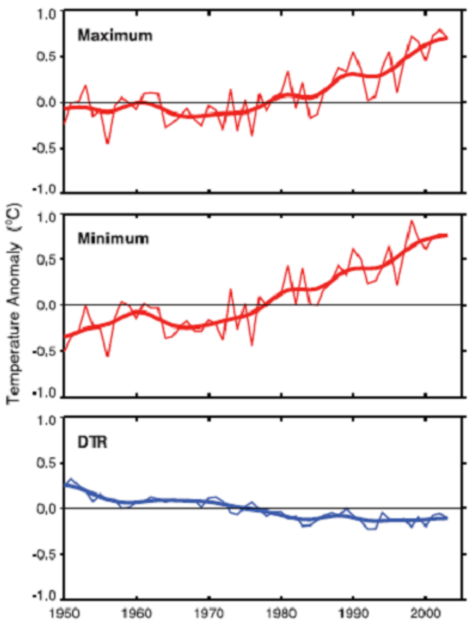


Fig. 3. The average annual anomalies of maximum and minimum daily and daily temperature amplitudes in the period 1950-2004
Source: [9]

An increase of the temperature by 2.5°C means that the current number of 850 million people suffering from chronic hunger will increase by another 50 million. A temperature higher than the current one is also a huge epidemiological risk and danger due to the spread of infectious diseases by insects. Higher temperatures contribute to the development of disease-carrying insects, which in this case will be able to reach many other regions and will spread the disease even where it has not previously been a major threat. Climate changes have a significant impact on the environment and its ecosystems. By 2050 it is estimated that up to 1/3 of the presently living species can be extinct. Polar bears, seals, walruses and penguins are particularly threatened. The boundaries of ecosystems shift, which results in animals not being able to adapt to the new conditions imposed on them and begin to die out.

Public awareness and European programs

Lack of knowledge and disregard for the problems associated with climate changes still result in insufficient action. An example of this is a 2007 survey conducted by Ipsos MORI in the UK, which revealed that 56% of citizens think scientists are still questioning climate change. The poll suggests that terrorism, graffiti, and crime are more alarming than climate change [10].

Table 1. The social perception of the existence and significance of global warming in the world and in the United States

View	% agreeing	Applicable/Year
Global warming is likely taking place.	85	USA/2006
Global warming is likely taking place.	80	USA/1998
Human activity is a significant cause of climate change.	71	USA/2007
Human activity is a significant cause of climate change.	79	World/2007
Climate change is a serious problem.	76	USA/2006
Climate change is a serious problem.	90	World/2006
Climate change is a serious problem.	78	World/2003
It is necessary to take appropriate action quickly.	59	USA/2007
It is necessary to take appropriate action quickly.	65	World/2007

Source: Ipsos MORI poll from June, 2007 in the UK

A report published by the European Environment Agency titled "Climate change, impacts and vulnerability in Europe 2012" stated that average temperatures were rising throughout Europe, and there was also a decrease in precipitation in the southern regions and an increase in precipitation in Northern Europe. Greenland's ice cap, Arctic sea ice, and many glaciers in Europe are melting, most of the permafrost is warming up, and the extent of the snow cover has decreased significantly. There is a high likelihood that in the future we can expect further negative consequences of global climate change, which will have a significant impact on the global economy [11]. This implies the need to take steps at several levels, at the local, regional and national levels. The size and the strength of the negative effects depend to a large extent on the socio-economic, geographical or climatic conditions of the region [12]. The European Union report shows that all European countries are exposed to sudden and unpredictable climate changes, but not all regions are equally affected. The effects of climate change will significantly contribute to increasing social disparities across the EU. We must pay close attention to the social groups and regions that are most at risk and that are already in a difficult situation.

Therefore, to reduce the effects of climate change, many joint adaptation projects have been developed between countries, regions or cities. Most of these types of programs are partly or fully financed by the European Union. An example is the 2014-2020 Research and Innovation Framework Program Horizon 2020, with a budget of more than 77 billion euros [13]. This program is intended to fund particularly small and medium-sized enterprises, which can be pioneers in developing projects and services to combat climate change, by exploiting the opportunity to conduct business around the world. These innovative strategies aim to promote a low-emission economy that is immune to climate change, and to promote sustainable development. Another program is LIFE +, whose main objective is sustainable development of the environment through the implementation and updating of community policies [14]. These actions are supported by EU funds and international institutions, including the European Investment Bank and the European Bank for Reconstruction and Development.

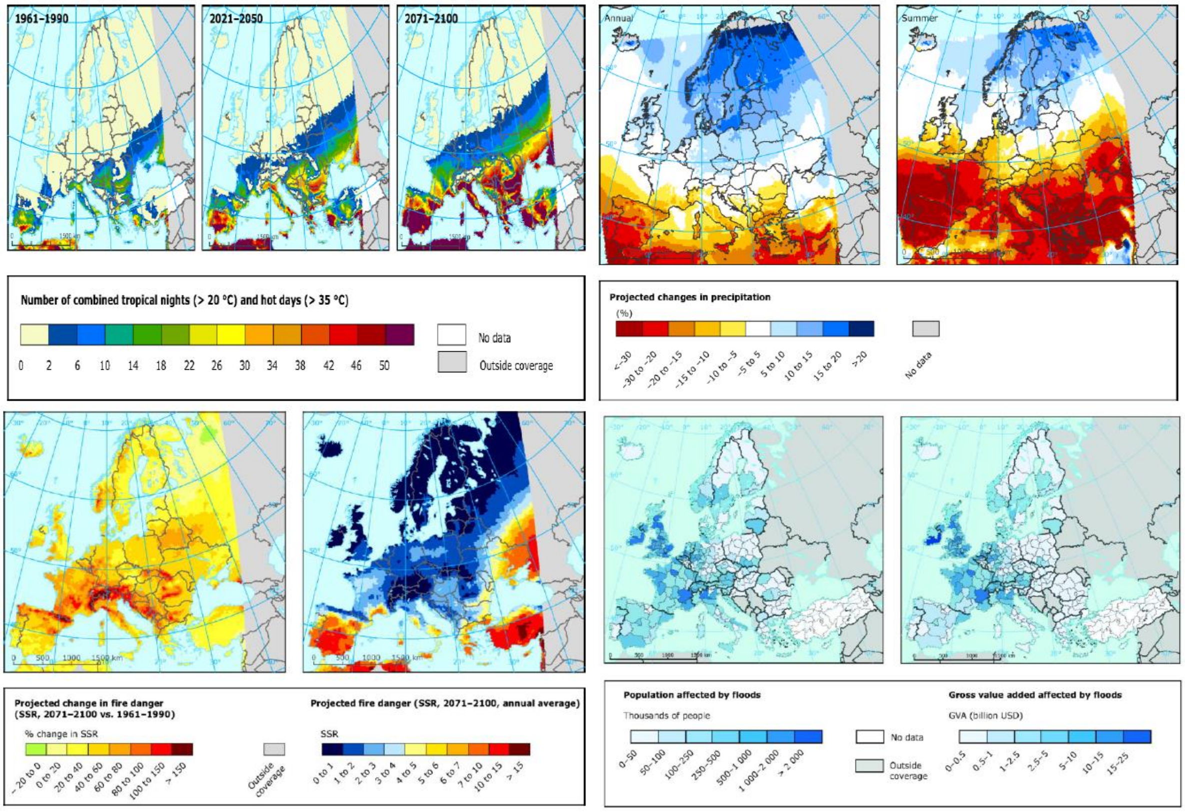
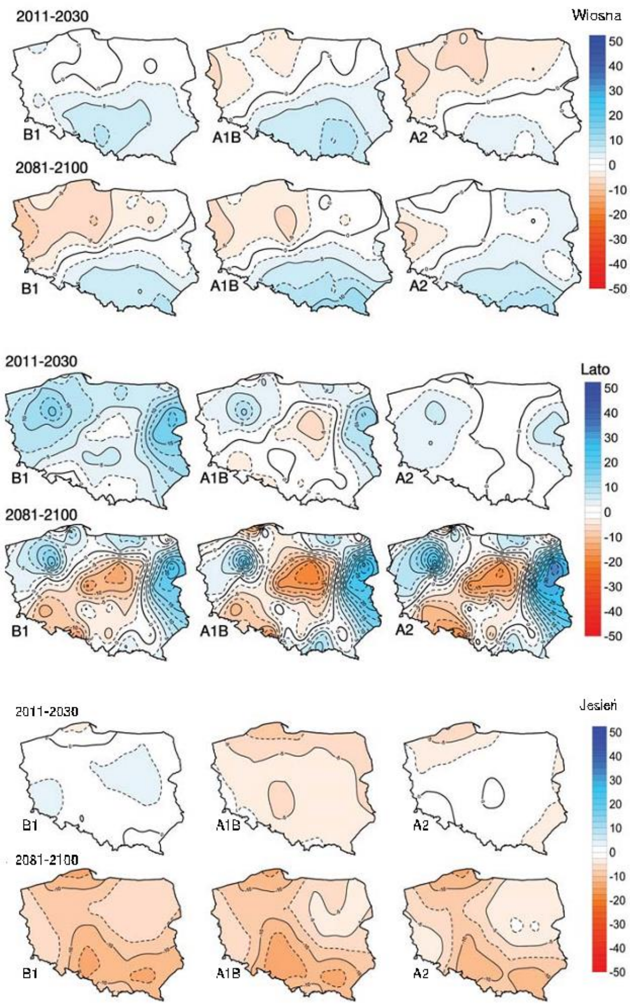


Fig. 4. The predicted effects of climate change and the related risks. *Based on the EEA report on the effects of climate change and vulnerability in Europe (2012)*
Source: [15]

Most industries, a significant proportion of the economy, global agriculture, and tourism are either directly or indirectly dependent on climatic conditions. One of the many examples of the effects associated with the changes are disturbances in the water management of ecosystems, the impact of heavy rainfall on the sudden rise of groundwater levels, and thus the impact of this process on surface water quality (Figure 4) [16].

Climate changes in Poland

Rapid climate change and unexpected weather anomalies like hurricanes, tornadoes, high temperature fluctuations, violent precipitation, and long-lasting droughts have become a reality in the last dozen or so years. Because of its geographic location, Poland is in a place conducive to the clashing of various masses of air, resulting in the formation of extremely different weather conditions, and consequently affecting the climate of our country. Poland's climate is characterized by high volatility and significant fluctuations, which can be exemplified by the recent turn of the weather. Warm winters, hot and rainy summers, and a short autumn and spring have a significant impact on the environment and thus on the economy. The lack of rainfall, low humidity, droughts and previously unprecedented temperatures are of great importance for all ecosystems and water relations in the surrounding region. Such phenomena are particularly noticeable in southern and southeastern Poland. According to scientists from the Institute of Meteorology and Water Management, the main cause of this situation is the process of climate change. Global weather changes affect the climate situation on both the regional and national levels. In the future, there will be significant changes in the hydrological cycle. The results of these changes will have a significant impact on the environment of the whole country.



Wiosna – Spring; Lato – Summer; Jesień - Autumn

Fig. 5. A scenario of change of the sums of rainfall in Poland in spring, summer and autumn season for the periods 2011-2030 and 2081-2100
Source: [17]

An analysis of the average annual precipitation in Poland from the last decade indicates a significant decrease in the so-called average annual precipitation in the southwest of the country by almost 5% and an increase of the average annual precipitation in the east by about 4% (Fig. 5). It must be stressed, however, that in the case of temperature, all forecasts jointly indicate growth tendencies, whereas in the case of precipitation the results are significantly different from one another. Despite the ambiguity of forecasts, it is necessary to consistently improve the system of water resources management in Poland.

Energy crops and climate change

Extreme climatic events that are widespread around the globe lead to a significant decrease in crop yields, including energy crops. Human activities increase the intensity of the natural greenhouse effect. This leads to significant changes in the temperature values and to related phenomena taking place throughout the climate system. The last decade of the 20th century was the warmest in the whole century. Hitherto unrecorded temperatures, torrential rains, unprecedented droughts, hurricanes, exceptionally warm and snow-free winters, hot summers affect food production all over the world. The relationship between agriculture and the climate is direct and indirect. Because of direct exposure, higher temperatures modify the uptake of nutrients from the substrate and increase the plants' demand for water, the soil evaporates faster, and the plants breathe more deeply (the process of evapotranspiration). As the temperature rises, the amount of water vapor in the air also changes, the level of matter content decreases and the soil exhibits a smaller water storage capacity. These factors hamper the growth of plants including energy crops. Both indirect and direct temperatures endanger crop yields. If a temperature range that is optimal for a given plant is exceeded in a region, the plant usually reacts negatively, resulting in reduced yields. Most plants are sensitive to high air temperatures. A temperature of 45-55°C for at least 30 minutes causes leaf damage in most plants. Even lower temperatures (35 to 40°C) can be destructive to plants if they persist for a long time. A temperature above 36°C can make corn pollen die, while a temperature of about 20°C hampers the formation and growth of potato tubers. The susceptibility to damage by high temperatures is different at different stages of plant development. Plants in the early stages of development are particularly sensitive to extreme weather phenomena. High temperatures are very harmful also in the reproduction phase, for example for corn during the corymb stage, for soybeans during flowering, and for wheat when the ears fill. On the other hand, it is also possible that higher temperatures may accelerate the growth of some plant species, as predicted for the staghorn sumac.

There is a growing deficit of water in the EU countries, which already has a very low nutrient content [20]. Drought causes wilting and slows down the development of plants, and changes the proportions of nutrients (carbon/nitrogen) contained in them, thus reducing the resistance to nematodes and insects. Weakened plants are more prone to attack by fungal pathogens, especially in shoot and root areas. Dry and warm weather is conducive to the growth of insect populations and epidemics of viral diseases, such as the locust plague associated with drought in Mexico (1999). Energy crops can suffer most if the dry periods occur during important phases of plant development, such as the reproduction phase. Most plants are particularly sensitive to water stress during flowering, pollinating and sprouting. The effects of drought can be avoided, for example by early planting of fast-growing plant varieties. Weeding and the introduction of microorganisms beneficial for the soil environment [16-20] can also be used to maintain proper soil moisture.

Precipitation, which is the primary source of moisture in the soil, is probably the most important factor in plant yield. Climate models forecast an overall increase in the average amount of precipitation in the world, but their results also suggest the possibility of a change of precipitation regimes in many places. Climate changes can cause an increase or decrease in the total precipitation in different seasons. Water management of energy crops is sensitive to factors such as higher temperatures, dryer air, and higher wind speeds, which accelerate evapotranspiration during the day and change its seasonal pattern. Drought is not only caused by reduced rainfall, but may also be the smaller amount of snow in winter and early melting of snow in spring. In dry regions, this may reduce the outflow of water in rivers and reservoirs used for irrigation of fields during the vegetative season. Periods of high relative humidity, frost or hail may also affect yields. Heat stress and water stress often occur together and act synergistically. Usually they are accompanied by high levels of solar radiation and strong winds. Under drought conditions, crop plants close their stomata to limit transpiration. As a result, the temperature inside the plant increases, which can cause damage.

Precipitation is probably the most important factor in determining how plants respond to pests and diseases. Very wet summers can cause lower yields, and water-soaked soils cause root rot and higher air humidity is conducive to increased pests and diseases, especially in the early phases of development. Rapid downpours can damage younger plants as well as accelerate soil erosion. The degree of damage to agricultural crops depends on the duration of rainfall and flooding, as well as the plant development phase and the air and soil temperature. Increased air humidity is conductive to epidemics and the spread of pathogens, such as the famine caused by rice brown in Bengal where 2 million people died in 1942. The yellow rust epidemic in China's most important manufacturing regions contributed to famine in the 1960s. Movement of soil due to increased erosion and simultaneous surface runoff causes the spread of pathogens to new areas. Pest infestations often coincide over time with changes in weather, such as early or late rains, drought or excessive rainfall. Warm and humid conditions are conductive to the development of most pests. Plants weakened by water deficit during drought are more easily attacked by pests such as the Asian lady beetle compared to plants that are not exposed to such stress.

The climate also affects the effectiveness of pesticides used to combat or prevent pest infestations. The intensity and duration of rainfall determines how long pesticides remain active and to what extent. In turn, temperature and light affect the length of their effective operation by accelerating their chemical degradation. Most analyses confirm that in the changing climate, pests can become more active than they are today and can increase their geographical range. There is concern that more chemicals will be used in agriculture in the future, and this will have health, environmental and economic consequences. Hence, it is necessary to draw attention to the ecological nature of crops.

The climate affects not only the crops, but also weeds that compete with crops for nutrients in the soil, for light and for space. Drought increases the competition between crops and weeds for the water contained in the soil, while high humidity promotes the spread of weeds.

The advantage of investing in renewable energy sources is that they are the projects with the lowest level of risk in the long run. They can also result in energy independence and security of a given area, communes, and voivodeships of the whole country. They can contribute to improving the energy supply of areas with underdeveloped energy infrastructure, particularly areas prone to high unemployment, which will also create new jobs [26]. In practice, the use of local sources of energy also means subsidizing at the local, communal, county or voivodeship level. The cultivation of energy crops significantly reduces CO_2, has a positive influence on the landscape, reduces fossil fuel consumption, and thus minimizes costs.

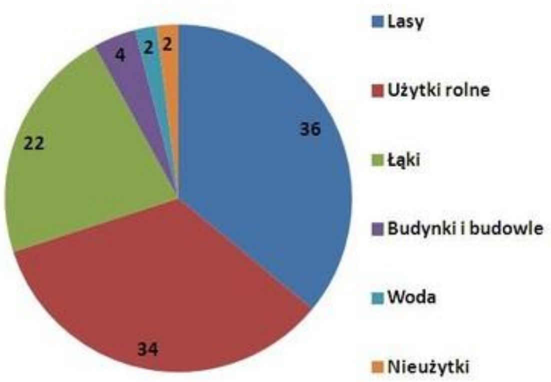
Poland, as a member of the European Union, must reduce emissions of greenhouse gases according to the previous findings. One of the most important ways to execute this task is to introduce and disseminate renewable energy sources, especially replacing some of the traditional transport fuels with biofuels, and replacing coal with energy crop biomass.

The high interest in energy crops is due to many factors. The desire to reduce CO_2 emissions, the occurrence of extreme weather phenomena, rapid growth and resilience to these phenomena, relatively low financial outlays for obtaining energy, numerous co-financing and projects have allowed for the creation of new directions in agricultural production and in the economy itself. The most commonly used raw material to produce biofuels is waste wood or straw. This condition will persist until the intensive development of energy crops.

In Poland, the most popular plants used in the so-called agricultural energetics include basket willow *(Salix viminalis)* Sida *(Sida hermaphrodita),* corn (Zea *mays),* Jerusalem artichoke *(Helianthus tuberosus), giant miscanthus (Miscanthus sinensis gigantea),* giant knotweed *(Polygonum sachalinense),* and Japanese rose *(Rosa Multiflora*). The latest forecasts indicate that soon, the supply of biomass in the energy market in Poland will be supplemented by the widespread use of energy crops plantations, established and operated on land not yet used by agriculture. Based on recent research, it can be stated unequivocally that the area of energy willow cultivation in the coming years will grow to a significant extent. Most of the plants used in bioenergetics are plants with low soil requirements, and an advantage of growing such plants is the chance to develop many barren lands in Poland.

The climatic changes observed so far in the country are conducive to increasing the potential usefulness of areas for production of energy crops and introducing into the cultivation of thermophilic species like sorghum, sunflower, and soybeans. Higher temperatures, longer growing seasons, and an increase in the sum of precipitation result in an increase in the productivity of these crops and do not adversely affect the grain and grass used in renewable energy production. The observed increase in air temperature contributes to the extension of the vegetation period by approximately 10 days. This influences the change of the dates of establishing energy plantations and the period of other agrotechnical works. For example, in the new climatic conditions, the dates of spring cereal sowing will be accelerated and the winter cereal, delayed by about 3 weeks. The harvest of cereals for energy needs may be one to four weeks earlier. Improved thermal conditions and a warmer zone moving northward increase the chances of growing thermophilous plants in the central and northwestern parts of the country. The increase in temperature by another degree will result in the absence of thermal barriers in Poland to grow medium-late corn. However, the decreasing availability of water in some areas and the increased irrigation needs in the conditions of more frequent droughts in the summer months will require a change in the assortment of cultivated energy crops. It will be necessary to replace the plantations existing in these areas, requiring humid soils (basket willow and corn), with plants with low water content requirements, such as silphium, millet, Virginia mallow, and sorghum. So far, the forecasts presented are not clear, some indicate growth, and others indicate a decline in yields in the changing climate.

The problem of growing energy crops in the changing climatic conditions of Poland will be the acceleration of the growth rate of weeds like that warmth and the emergence of new and hard to exterminate pests (the corn rootworm, the corn earworm), as well as the increase in the populations of pests with low harmfulness (aphids, Oscinella frit, root fly, Phytomyza pubicornis, thrips). Mild winters will increase the risk of some diseases. This will require the intensification of the use of energy crop protection agents against diseases and pests, which in the case of the existing integrated crop system is costly and difficult due to the limited assortment of pesticides. Another problem related to weather anomalies is the increasing variability of energy crop yields, which requires growing a wide range of crops to ensure a steady delivery to the recipient.



Lasy – Forests; Użytki rolne – Arable land; Łąki – Meadows; Budynki I budowle – Buildings and structures; Woda – Water; Nieużytki – Barren land

Fig. 6. The territory of Poland broken down into developed lands
Source: [21]

According to Eurostat data for 2013, Poland is mainly covered by forests, which account for almost 36% of the territory (Fig. 6). A relatively large part of Poland, approximately 34%, is also covered by agricultural land. Barren land in Poland accounts for almost 2% of the area. It is worth noting that on average in the European Union a total of 6% of the territory of the various countries is wasted.

It is also worth stressing that plantations of energy crops and all sorts of related treatments are covered by many aid programs, which include the SAPARD Program, the PHARE Fund, the EU LIFE+ program, the EU HORYZONT 2020 program, which will be launched in 2014. Many national and regional institutions are providing co-financing, such as the Voivodeship Environmental Protection and Water Management Fund [22] or the Rural Area Development Program.

The future of the climate
Earth's climate is a highly complex process, and to understand its very complex mechanisms and dependencies, scientists need to use general circulation models (GCM). This is a mathematical model describing the behavior of the climate based on the equations of fluid mechanics and other equations from the realm of physics and chemistry, describing processes important for climate change (Fig. 7).

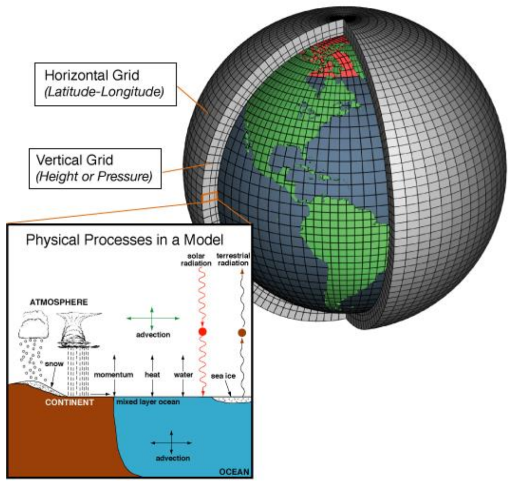
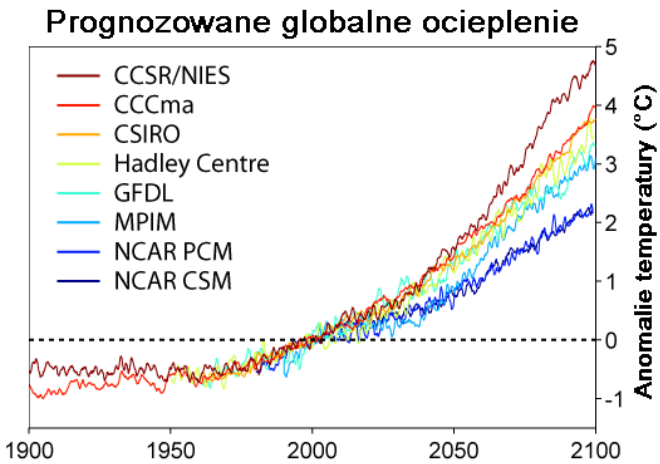


Fig. 7. An exemplary model describing the behavior of the climate based on the equations of fluid mechanics and other equations from the realm of physics and chemistry, describing processes important for climate change
Source: [23]

The use of this type of operation allows for tracking and investigating many processes taking place in the atmosphere, and to analyze possible interactions. These models allow for determining the directions of the changes in the coming years. An example of this type of simulation is the use of the variant with the ever-increasing concentrations of greenhouse gases in the atmosphere. Another example of a simulation that considers the increase in CO_2 in the atmosphere is the impact of sulfur aerosols. These compounds dissipate and reflect sunlight back into space and cause cloud formation, and this simulation also includes the temperature reduction factor. At present, several models of this type have been developed, a significant part of which are used to predict the impact of increased concentrations of greenhouse gases on the world climate. GCM results unequivocally indicate an increase in the average temperature between 1.4°C and 5.8°C (Fig. 8). Both the increase of the amount of aerosols in the atmosphere and the increase of the amount of CO_2 will greatly reduce the amount of sunlight reaching Earth, and thus cool the planet.



Prognozowane globalne ocieplenie – Forecast global warming; Anomalie temperatury – Temperature anomalies

Fig. 8. Predicted increase in temperature according to different general circulation models
Source: [24]

The general circulation models also predict average rainfall in the world to grow by about 520%. They also allow to indicate regions in the world where warming can be much higher than the global average. Minimum temperatures in winter and at night will continue to rise faster than average temperatures. Disorders in the global water economy will greatly increase the frequency of anomalies such as droughts and floods. The increase in the occurrence of snowless winters, and consequently the decline of spring thaw, will potentially increase the effects of spring and summer droughts. Despite the many doubts and criticisms of the unrefined circulation models by scientists, it is obvious that the above weather disturbances will directly affect the world economy, particularly agricultural production. It is very likely that many regions of the world today characterized by high productivity will have to abandon crop production. The very likely changes in air temperature and water circulation in the natural environment will have serious consequences both for the functioning of most ecosystems and for the human economy. As a result, the frequency, territorial extent, and intensity of weather disasters will increase significantly. The only opportunity to minimize the effects of anomalies and losses in food production is to adapt agriculture and its agro-technology, forest management, water management, and other sectors of the economy to the altered climatic conditions.

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CLIMATE CHANGE AND GROWTH OF ENERGY PLANTS

Abstract
Atmospheric circulation, temperature, hydrological cycles, and the impact of solar radiation affect condition of all life on Earth. Rapid climate change may have positive and negative effects, forcing people to create new solutions in the field of industry, agriculture, and construction. Developing appropriate strategies for this type of crop plants can help reduce the negative effects of global environmental change.

Key words
climate change, global adaptation, energetic plants, energy demand