SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2025
ORGANIZATION AND MANAGEMENT SERIES NO. 233

SELECTED GREENHOUSE GASES AND THEIR PRACTICAL USE IN SUSTAINABLE DEVELOPMENT

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Purpose: The aim of this article is to identify the main greenhouse gases, their impact on climate change, and present ways to prevent unfavorable climate change. It also demonstrates how these gases can be used in both scientific research (explaining the mechanisms of global climate change) and practical applications (intensifying food production).
Design/methodology/approach: To identify the main greenhouse gases, used research results determining their ability to absorb electromagnetic radiation. The identified main greenhouse gases - H_2O and CO_2 provide a starting point for climate control efforts and the intensification of food production.
Findings: A model of the Earth's climate change mechanism was developed, which may be necessary to implement optimal climate parameters for humans. A method for using power plant exhaust gases to intensify food production was proposed.
Research limitations/implications: Research is needed on the impact of forest area and type on increasing water accumulation on land. Research on the impact of CO_2 concentration and thermal conditions on plant growth rates is also needed.
Practical implications: Climate research is time-consuming due to the significant inertia of phenomena occurring on Earth and in the Earth's atmosphere. However, from a long-term perspective, it is the most important. Research on increasing the speed of plant growth can be conducted in the near future. The pilot facility will provide information on the effectiveness and nutritional value of food.
Social implications: The research will undoubtedly impact quality of life. It will raise the prestige of scientific institutions and industry. Public confidence in the activities being implemented will increase, contributing to easier forecasting of the future.
Originality/value: This article presents a new way to assess climatic phenomena occurring on Earth. For the first time, it presents a mechanism of climate change on Earth, driven by water. It proposes a unique approach to intensifying agricultural production that could contribute to improving food quality.
Keywords: greenhouse gases, greenhouse effect, climate change, global warming, sustainable development, food production.
Category of the paper: Research paper.

1. Introduction

It is widely accepted that CO_2 emissions are responsible for the greenhouse effect and global warming. The effects of global warming are demonstrated by drifting icebergs (figure 1), bursting glaciers (figure 2), and droughts causing crop failures and famine (figure 3).

Figure 1. Glaciers and icebergs.

Source: Wikimedia Commons.

By 2100, glaciers are expected to lose an average of one-third of their mass, and some mountain ranges are projected to lose as much as 80% of their glaciers, with some disappearing completely. Global glacier shrinkage, permafrost thawing, snow cover thinning, and Arctic glacier drift will continue due to rising surface air temperatures, warns the UN International Oceanic and Climate Change Committee (IPCC) in its latest report, "The Ocean and Cryosphere in a Changing Climate" (Komitet Naukowy ONZ (IPCC).

Figure 2. Glacier cracking attributed to CO_2.

Source: Komitet Naukowy ONZ (IPCC); Dwutlenek węgla uszkadza lód…

Due to drought, recent years have seen an increase in migration in Africa, including towards Europe. This was due, among other things, to food shortages. Nearly 45 million people are at risk of starvation. Hunger and lack of drinking water contribute not only to increased migration but also to armed conflicts. Between 2006 and 2010, drought caused a collapse of agriculture in northeastern Syria and a mass migration of people from rural areas to cities (Jarosiński, 1996).

Figure 3. Consequences of drought and crop failure.

Source: Jarosiński, 1996.

Climate change is unquestionably occurring. Figure 1 shows a graph of changes in the Earth's average temperature from 1850 to 2022. Data were obtained from various scientific centers: HadCRUT from the Met Office Hadley Centre, NOAAGlobalTemp from NOAA NCEI, GISTEMP from NASA GISS, ERA5 from ECMWF, JRA-55 from JMA, and Berkeley Earth (Globalne ocieplenie…). The graph illustrates temperature change relative to "pre-industrial" times, which are conventionally referred to as the period 1850-1900. Dynamic industrial development is expected to cause increased emissions of greenhouse gases – mainly CO_2, responsible for global warming.

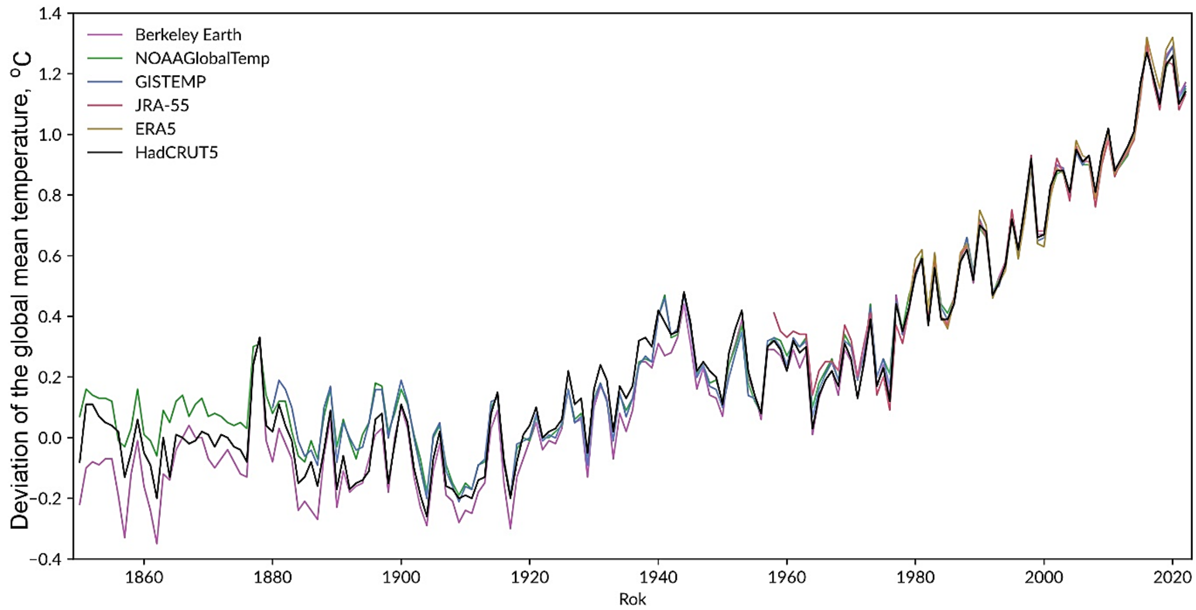


Figure 4. Temperature anomalies of land and ocean surfaces in relation to the period 1850-1900.
Source: Globalne ocieplenie…; Zmiana klimatu 2013…; Wikimedia COMMONS.

The invention of the steam engine by James Watt (1763) sparked a rapid industrial development, in which, alongside steam engines, boilers generating steam at predetermined temperatures and pressures played a key role. The primary fuels were hard coal and wood. After Ignacy Łukasiewicz refined crude oil (1852), heating oil gradually began to be used. Although the late 19th century witnessed weather anomalies (Fig. 4), these were not caused by CO_2 emissions. While these increased due to industrial development, the increase was small on a global scale. In the early stages of industrialization, forests were rapidly deforested for two main reasons: wood was the primary building material, and steam engines processed this raw material with high efficiency. This led to the clearing of vast areas that now resemble steppes. This is particularly evident in North America, where forested areas are primarily national parks. Table 1 lists greenhouse gases and their contribution to the greenhouse effect. Unfortunately, not all greenhouse gases are listed, but particular emphasis is placed on CO_2.

Table 1.
Types of greenhouse gases and their contribution to the greenhouse effect

Gas name	Length of time in the atmosphere in years (Jarosiński, 1996)	Contribution to the greenhouse effect (http://ekoproblemy.webpark.pl)	Infrared radiation absorption efficiency in relation to CO_2	
			according to (Jarosiński, 1996)	according to (http://ekoproblemy.webpark.pl)
Carbon dioxide (CO_2)	50-200	50%	1	1
Methane (CH_4)	10	18%	21	30
Freons	65-130	14%	12400-15800	10-20000
Ozone (O_3)	-	12%	2000	2000
Nitrogen oxides (NO_x)	150	6%	206	150

Source: Jarosiński, 1996l; http://ekoproblemy.webpark.pl; Lewandowski, Klugman-Rodziemska, 2017.

The greenhouse effect is often associated with the sun's emission of electromagnetic radiation towards the Earth. This is only partially true. The sun alone would not guarantee life on Earth. For example, the temperature on the moon, during sunlight, can reach 127°C, while at night, in darkened areas, it drops to -173°C. This occurs as a result of thermal energy radiating into space at night, energy stored in the sunlit part of the moon during the day. The lack of an atmosphere is blamed for the radiation of thermal energy. If the moon had an atmosphere, temperature oscillations between day and night would be significant anyway, as it has no internal heat source.

2. The greenhouse effect

A simplified model of the greenhouse effect occurring during household chores is presented in Fig. 5.

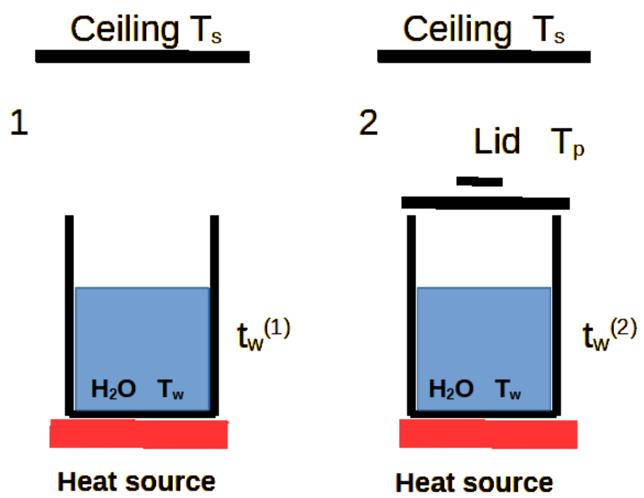


Figure 5. Simplified model of the greenhouse effect in a household.

Heat exchange between the vessels and the environment is the same for the first and second vessels, except for the heat radiated by the water surface. For example, in the first vessel, heat is radiated to the ceiling

$$\dot{q}_r^{(1)} = \sigma\varepsilon(T_w^4 - T_s^4), \quad (1)$$

in the second vessel - for the lid

$$\dot{q}_r^{(2)} = \sigma\varepsilon(T_w^4 - T_p^4), \quad (2)$$

where:

σ = 5.67·10−8J/sm2K4 is the Stefan-Boltzmann constant;

ε – emission power of the body (0 ≤ ε ≤ 1);

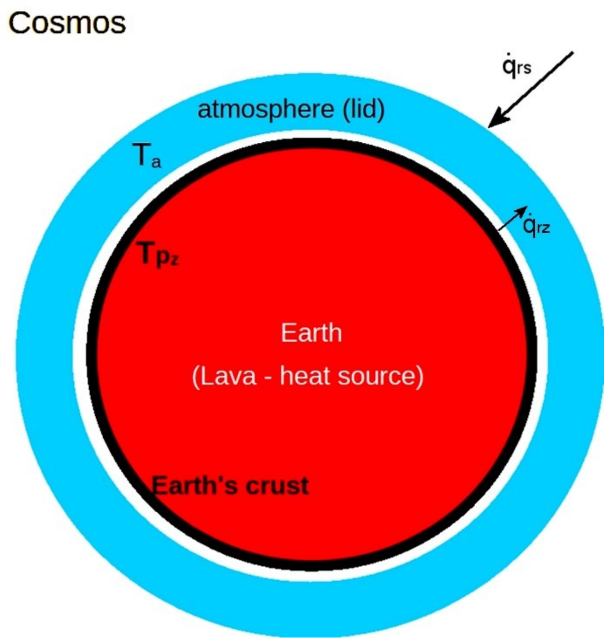
Tw – water temperature, K;

Ts – ceiling temperature, K;

Tp – lid temperature, K;

tw(1), tw(2) – water heating time are the boiling temperatures in the first and second vessels, respectively, s.

The heat flux radiated from the first vessel is greater than the heat flux radiated from the second vessel, because Ts < Tp. Therefore, the water in the second vessel will heat to boiling point faster than in the first vessel (tw(1) > tw(2)). We say that the lid generates the greenhouse effect. This phenomenon is very common in households (cooking food, brewing herbs, coffee, etc.). A similar situation exists for the globe, where the atmosphere takes over the function of the lid. The difference is that the lid—the Earth's atmosphere—is heated not only by the Earth but also by the Sun. A simplified model of the Earth's greenhouse effect is shown in Fig. 6.



$\dot{q}_{rs}$, $\dot{q}_{rz}$ – solar radiation flux and earth radiation flux, respectively.

Figure 6. Simplified model of the Earth's greenhouse effect.

The Earth's interior is a vast reservoir of energy in the form of magma, with temperatures reaching several thousand degrees Celsius. It acts as a radiator, heating the Earth's crust and radiating thermal energy into space. The size of this "radiator" is demonstrated by the fact that it constitutes approximately 97% of the Earth's volume. The remaining portion is the Earth's crust, which has an average thickness of approximately 50 km. For comparison, the ratio of the Earth's crust's thickness to its radius is approximately 0.0078, and for a chicken egg, the ratio of the shell's thickness to the egg's radius is 0.0139. This simple comparison illustrates just how powerful a radiator we live on.

Therefore, the Earth's atmosphere is heated by both the Sun and the Earth's surface. Its temperature, and therefore the magnitude of the greenhouse effect, depends on the ability of the gases comprising the atmosphere to absorb electromagnetic radiation energy.

3. Greenhouse gases

Gas molecules absorb electromagnetic radiation only at frequencies equal to their resonance frequencies. Not all gases absorb this radiation to the same extent, as their molecules have different resonant vibration frequencies. Therefore, gases absorb electromagnetic radiation energy only in certain wavelength ranges. As a result of absorbing radiation energy, the molecules increase their thermal vibration amplitude, increasing their internal energy, which consequently increases the gas temperature.

Figure 7 shows the solar radiation spectrum before (yellow) and after penetration through the atmosphere (red), with the interactions of greenhouse gases highlighted (Lewandowski, Klugman-Rodziemska, 2017; Miłek, 2009). The ordinate of the graph – spectral irradiance – represents the value of the electromagnetic radiation flux incident on a unit of surface area in a given spectral range, or, in other words, the radiant power per unit of spectral width.

Radiation reaching the Earth's surface has a significantly lower intensity than that entering the atmosphere. The radiation spectrum exhibits characteristic "defects" caused by absorption of radiation by gases. The greatest reduction (notch) in electromagnetic radiation is caused by H_2O. Figure 8 shows the characteristics of solar radiation and Earth's radiation (as a perfectly blackbody with temperatures of 210-310 K). Below the spectra of the perfect blackbody radiation (solid lines) are the radiation spectra after passing through the atmosphere: for solar radiation, measured at the Earth's surface (red), and for radiation emitted from the Earth, measured in the upper atmosphere (blue). Transmission is the ratio of radiation passing through the atmosphere to the radiation that impinged on it. The graph shows that the atmosphere's efficiency in absorbing the Earth's surface radiation is high, ranging from 70% to 85%.

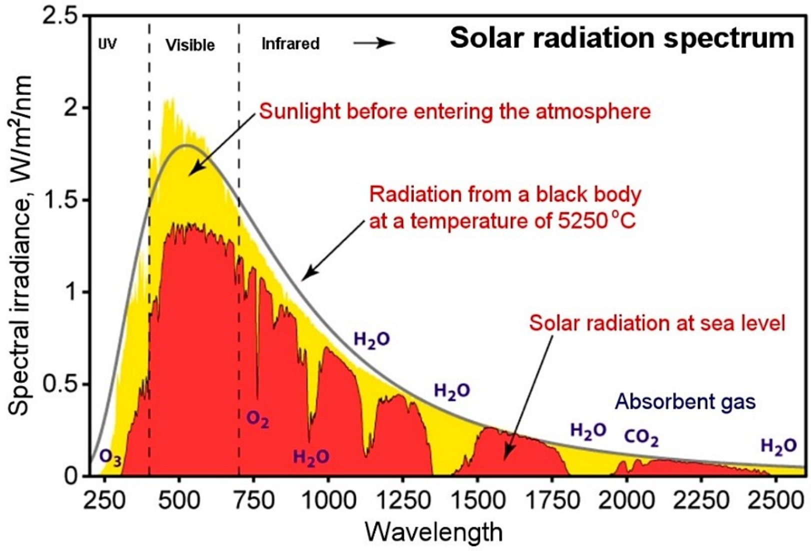


Figure 7. Solar radiation spectrum before and after penetration through the atmosphere with marked effects of greenhouse gases.

Source: (Miłek, 2009; https://upload.wikimedia.org/…).

Below the radiation spectra graph, the percentage share of radiation absorbed by the atmosphere is presented, and further below, the contribution of individual atmospheric components to the absorption of radiant energy.

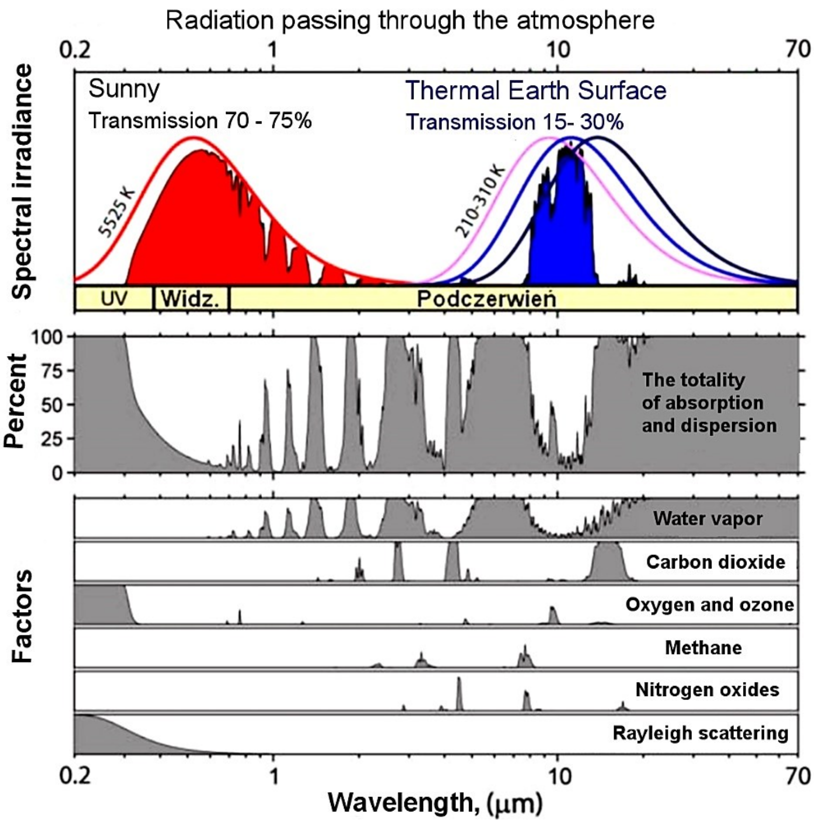


Figure 8. Spectra of the Sun and Earth radiation before and after entering the atmosphere, percentage graph of absorbed radiation, and the share of individual gases in absorption.

Source: Miłek, 2009.

A value of 100% indicates complete absorption of electromagnetic radiation in a given wavelength range. Among the individual greenhouse gases shown in Fig. 9 (CH_4, CO_2, H_2O, etc.), it can be seen that H_2O's share in the absorption of electromagnetic radiation energy is significantly greater than that of CO_2 (dark areas).

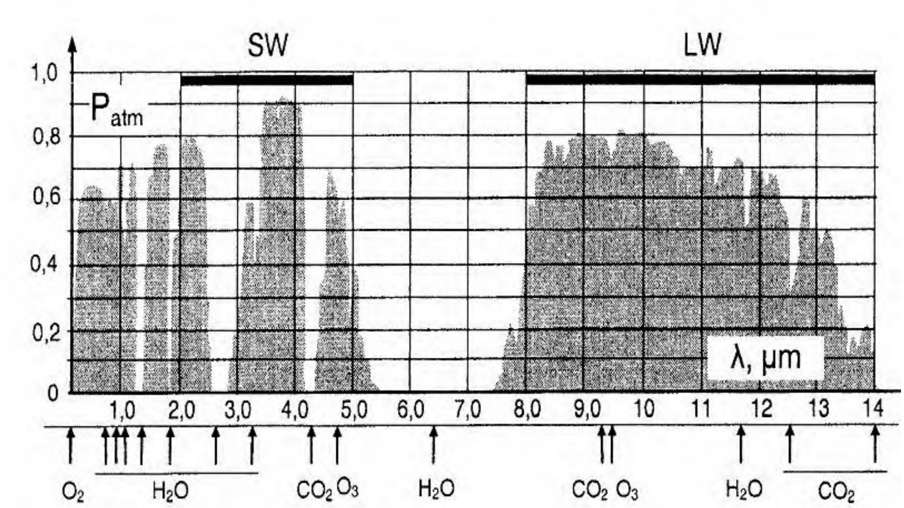


Figure 9. Radiation spectrum after penetrating a 1.5-kilometer section of the atmosphere.

Source: Miłek, 2009.

Figure 9 shows an even greater influence of H_2O in the absorption of thermal radiation (bright fields), which is the result of spectrum measurements after the radiation passes through a 1500-meter section of the Earth's atmosphere (Miłek, 2009).

Table 2 presents the contribution of the main greenhouse gases to the greenhouse effect. The media often emphasizes the contribution of CO_2 to the greenhouse effect, less frequently CH_4, ozone, or CFCs, but the main culprit of the greenhouse effect, H_2O, is almost always overlooked. It is precisely the change in the proportion of water in the Earth's atmosphere that generates climate change.

Table 2.

Contribution of H_2O and CO_2 to the greenhouse effect

Greenhouse gas	Contribution to the greenhouse effect, %
Water vapor (H_2O)	96,00
Carbon dioxide (CO_2)	2,44
Other gases	1,56

Source: Lewandowski, Klugman-Rodziemska, 2017; https://upload.wikimedia.org/wikipedia/commons/b/b7/Solar_SpectrumPL.png

Figure 10 shows the Earth's thermal envelope, composed of H_2O, which acts as a radiation shield that influences the amount of energy radiated by the Earth into space. Water in the Earth's atmosphere occurs primarily as water vapor and constitutes on average about 0.4% of the atmosphere's volume, although in the lowest layers, close to the Earth's surface, it can reach 1-4%. It is crucial for the hydrological cycle and climate regulation.

Figure 10. A radiation shield made of water creates the Earth's climate.

Source: Wikimedia Commons.

4. Balance CO2

The seas and oceans contain the most carbon dioxide, a result of both biological and geophysical processes. It is estimated that seawater contains approximately 132,000 billion tons of CO2. Approximately 330 billion tons are released into the atmosphere annually from the seas and oceans, so given the abundance of CO2 in these waters, there will be enough for many years to come. Vegetation on Earth assimilates approximately 400 billion tons of CO2, while humans contribute only 24 billion tons to CO2 production (industry, transport). For many years, a roughly constant CO2 level of 2,900 billion tons has been observed in the Earth's atmosphere. Therefore, the share of human-produced carbon dioxide in the Earth's atmosphere does not exceed 1% (Miłek, 2009). The above data are summarized in Table 3.

Table 3.
Estimated carbon dioxide balance on Earth

L.p.	Sources CO_2	billion tons
1	Seas and oceans	132000
2	Release from seas and oceans (per year)	300
3	CO_2 assimilation by plants (during the year)	400
4	Industry, transport (during the year)	24
5	Earth's atmosphere	2900

Source: Miłek, 2009.

It should be noted that the 2.44% share of carbon dioxide in the greenhouse effect (Table 2) refers to 2,900 billion tons of CO_2 contained in the Earth's atmosphere, while the human contribution to this effect, due to the introduction of 24 billion tons of CO2, is only about 0.02%. This value is within the margin of error of estimation and has no practical significance.

5. Climate change

As shown above, the Earth's climate is primarily influenced by water, or more precisely, its share in the Earth's atmosphere. The concept of the water cycle is well-known, and it is known that it is a closed system. However, the amount of water evaporating into the atmosphere can be regulated by retaining some of it on Earth. Plants naturally possess the ability to accumulate water on Earth, and it was water and plants that changed the Earth's climate. This continued until humans, recklessly, began to influence climate processes.

The mechanism of climate change is still unknown. While descriptions of individual climate epochs are available, there are no explanations for the causes of these changes. Many research centers attempt to track temperature changes (e.g., Fig. 4) and use these changes to predict future climate. This work is very tedious, time-consuming, requires extensive analysis, and the results are not entirely satisfactory.

Understanding the mechanism of climate change can significantly facilitate understanding historical climate changes on Earth. It is also possible to control and stimulate the Earth's climate so that future generations can pursue sustainable development without disruption.

The proposed mechanism for climate change on Earth below addresses these changes without human influence. The proposed mechanism is very general, and its individual components can be expanded based on existing geological knowledge. The process of climate change on Earth is illustrated in Figure 11.

The course of climate change can be summarized in four stages:

1. Climate cooling.
2. Ice age.
3. Glacial movement.
4. Post-glacial period, temperature increase.

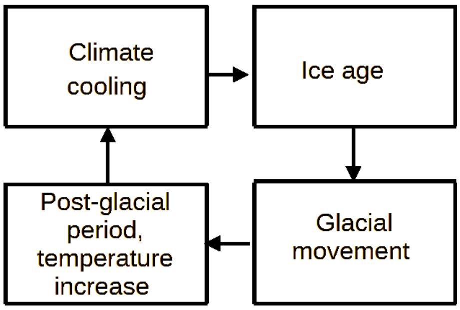


Figure 11. The mechanism of Earth's climate change without human involvement.

Climate cooling is a consequence of lush, uncontrolled vegetation. Green continents accumulated large amounts of water, and as a result, its share in the atmosphere decreased. The radiation shield weakened, and the Earth radiated significant amounts of energy into space. The Earth's temperature dropped, and glaciers began to form.

The ice age was a period of continuous increase in the thickness of the ice sheet. Glaciers varied in size depending on their location on the Earth, on mountain slopes or in valleys. The thick glacier cover impeded the transfer of heat from the Earth's interior to the surface. Ice sheets flooded near the ground and bedrock. The cohesion between the glaciers and the Earth's crust was progressively broken. This process was also exacerbated by solar radiation penetrating the glaciers, slowly but steadily heating the ground.

Glacial movements are the next stage of climate change on Earth, arguably the most important. Water at the glacier-ground interface acts as a lubricant, and massive glaciers begin to shift, carrying and burying everything they encounter. The enormous kinetic energy stored in glaciers means they can move significant distances, even several thousand kilometers. Forests are disappearing, and fallen trees are future coal deposits. The share of vegetation is decreasing, and the Earth's capacity to store water is diminishing. More water is released into the atmosphere. The greenhouse effect is intensifying, and the Earth's temperature is rising.

The post-glacial era is a new map of the Earth created by the formation of new landmasses. Temperatures rise, glaciers largely disappear, and seas and lands emerge with new boundaries. Conditions for fauna to thrive are created, and biological life is reawakening.

It's easy to see that the climate change process lacks a global warming phase similar to the one currently observed. Warming significantly different from that generated by the planet itself is unstable and dangerous for the Earth. Overheating of the Earth's crust could inhibit the development of fauna. A feedback loop is created, which could result in the biological annihilation of the planet. A hypothetical overheating scenario occurred on Venus. The physical parameters there indicate a highly advanced greenhouse effect. Furthermore, compounds have been identified on Venus that can only be produced by living organisms (NASA publikuje pierwsze zdjęcia Wenus…).

6. Conventional energy and agricultural production

Carbon dioxide is crucial for plant growth because it is the main raw material for photosynthesis, the process by which plants convert sunlight into energy. Carbon dioxide in the plant environment can stimulate growth, increasing photosynthetic efficiency and leading to higher yields, especially in controlled environments such as greenhouses. C3 plants, such as wheat and rice, can show particularly large yield increases of up to 40-100% at CO_2 concentrations between 800 and 1000 ppm. C4 plants, such as corn, can also experience yield increases, although usually smaller, of the order of 10-25% at similar CO_2 concentrations (Poudel, Dunn, 2023). Carbon dioxide constitutes 0.04% (400 ppm) of the atmospheric volume. Figure 12 shows the relationship between CO_2 and plant growth rate in greenhouse crops. Plants respond positively at concentrations between 700 and 1800 ppm, but higher CO_2 levels can cause plant damage.

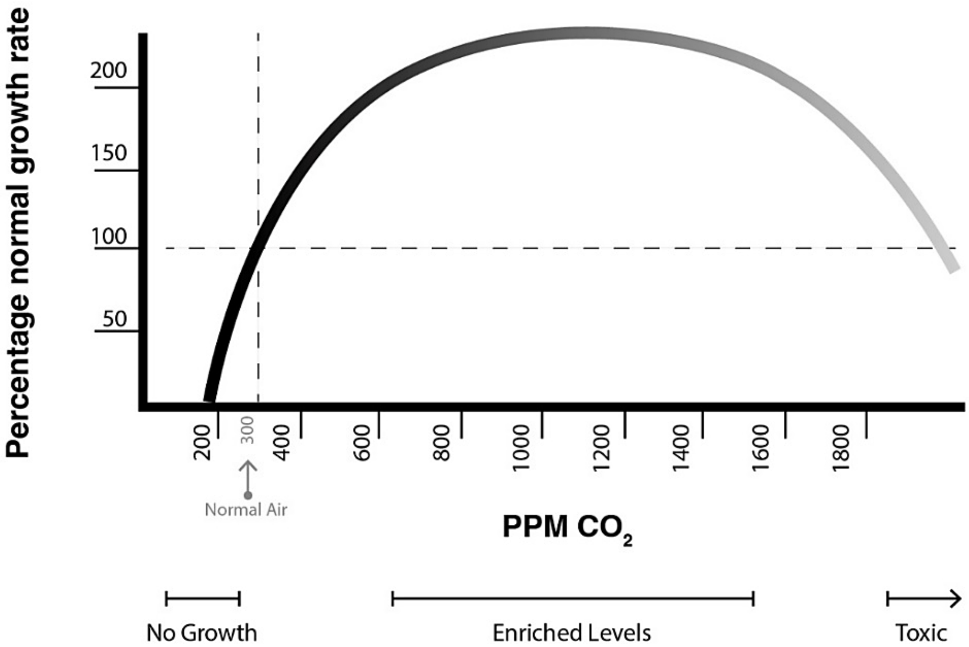


Figure 12. Relationship between CO_2 concentration and plant growth rate.

Source: Poudel, Dunn, 2023.

The data presented indicate that carbon dioxide is a valuable gas that can double or even triple the production of certain agricultural crops. This is important in the fight against hunger and the implementation of economic programs aimed at sustainable development. The practical use of carbon dioxide is implemented according to the simple diagram shown in Figure 13. The source of carbon dioxide is a CO_2 generator, and the cultivation area is an extensive system of greenhouses of any size.

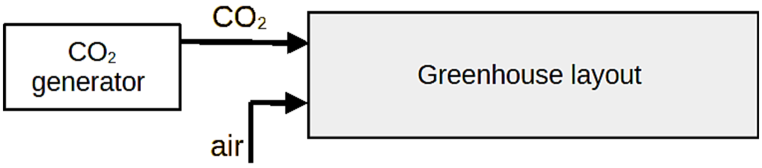


Figure 13. Use of carbon dioxide for agricultural production.

For large-scale crop production, CO_2 generators can prove too expensive. However, there is a much more advantageous solution: waste material, such as from combined heat and power plants (CHPs), namely exhaust gases. The CO_2 content in exhaust gases depends on the type of fuel used, but typically ranges from 8% to 12% for gas boilers, and can reach 10-12% in coal-fired power plants and CHP plants.

In addition to carbon dioxide, exhaust gases contain nitrogen, oxygen, and harmful components – primarily nitrogen oxides (NO_x), sulfur dioxide (SO_2), and dust. The removal efficiency of harmful components from exhaust gases is currently very high. Fabric filters eliminate dust from exhaust gases with dust removal efficiency exceeding 99.9% (https://1filter.pl/technika-filtrow-workowych/). The removal efficiency of nitrogen oxides from exhaust gases, i.e., exhaust gas denitrification, is over 95% (https://polskiprzemysl.com.pl/…; https://www.mokrosz.pl/…). NO_x removal from exhaust gases is carried out using SCR (Selective Catalytic Reduction) systems. The removal efficiency of SO_2 from exhaust gases reaches up to 90% (ttp://eomega.eu/…). These are very good results considering that exhaust gases are mixed with air to achieve the desired operating CO_2 concentration in the greenhouse. Using a combined heat and power plant has the additional advantage of providing process steam for heating the greenhouse. Figure 14 shows an example of implementing the principle of sustainable development – an energy plant integrated with an agricultural facility.

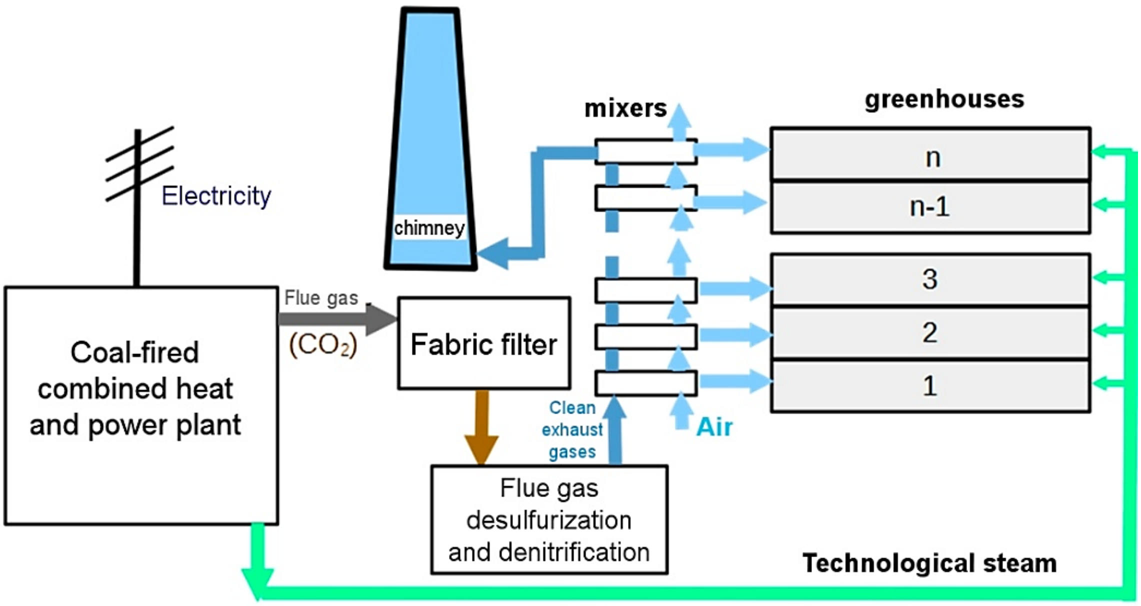


Figure 14. Energy plant integrated with an agricultural plant implementing the principle of sustainable development.

Modern exhaust gas purification methods ensure they have no negative impact on the environment. Exhaust gases are mixed with air in a dedicated mixer for each greenhouse. It is possible to adjust the CO_2 content appropriately for greenhouses growing different crops. Excess exhaust gases are discharged into the chimney. Process steam serves as a heating medium and is supplied individually to each greenhouse. Greenhouses intensify agricultural production without the use of chemicals that negatively impact living organisms.

7. Discussion

Global warming is a fact, and the main cause is the excess water in the atmosphere. Climate processes are characterized by significant inertia, meaning that changes are progressing relatively slowly, but halting these changes with the intention of reversing them is difficult and may prove impossible. The consequences are not difficult to predict.

Unfortunately, for years we have been observing growing public concern about the accelerating destruction of Polish forests, including the most valuable ones, such as the Białowieża Forest, the mountain forests in the Carpathians, the Świętokrzyska Forest, and the Bukowa Forest (Greenpeace, 2024; Synowiecki, 19.11.2024; Wielka wycinka w Polsce trwa…). While 27.7 million cubic meters of trees were cut down in Poland in 2000, this figure will reach 44.6 million cubic meters in 2022 (Rocznik statystyczny leśnictwa GUS, 2019, 2023). A similar situation likely exists in other countries. Tree felling in cities is also observed, and lawn mowing is common, as lawns dry out quickly and the ground loses water. The charm of greenery and flowers, as well as the microclimate so crucial during hot weather, are being erased, leaving behind patches of yellowed and dry grass. Despite the era of computerization, the amount of paper used is growing enormously and carelessly – periodic utility bills sent to millions of residents, online shopping and cardboard boxes, paper fillers for empty spaces in parcels, advertising, brochures, etc. In Poland, waste paper recycling is only 42% (Recykling papieru (makulatury)…).

As a result of such activities, enormous amounts of water are released into the atmosphere, intensifying the greenhouse effect and, consequently, global warming. However, carbon dioxide (CO_2) is blamed for this state of affairs.

Shutdowns and subsequent decommissioning of modern power plants, primarily fueled by hard coal, are planned. As demonstrated, the operation of these facilities has no impact on the greenhouse effect. Electricity suppliers are planning periodic shutdowns not only for individual users but also for businesses due to the inefficiency of renewable energy sources. Energy supplies will continue, but from backup sources at a significantly higher price. Some remaining coal-fired power plants are to assume the role of backup energy sources. Energy security has been threatened. More on this topic can be found in (Wójcik, 2008, pp. 28-32).

Generation and operating costs are rising. Achieving sustainable development may be very difficult.

The promotion of carbon dioxide as the cause of global warming is a classic example of the informational impact of technical systems on the environment. It's difficult to speak of information warfare here, as the environment does not undertake any significant informational activities. Informational impact on the environment is achieved methodically, utilizing knowledge from the interdisciplinary field of science known as cybernetics. Many forms of information transmission incorporate information transfer principles designed to effectively achieve intended goals. The goals of informational impact are not the subject of this paper. Methods of informational impact on the environment are presented in (Wójcik, 2013, pp. 163-185; Wójcik; 2011, pp. 344-355). Among the most frequently used information transfer principles are the principle of emotional arousal (glaciers, drought, global warming), mass and long-lasting impact, gradation, and alleged obviousness. Perhaps the most influential on the human psyche is the principle of alleged obviousness. It involves proving a thesis different from the one actually disseminated. The thesis that is actually disseminated is presented as an axiom that is not subject to discussion.

8. Conclusions

It's important to emphasize that the greenhouse effect is caused by an excess of water vapor in the atmosphere. While we can't change the process of evaporation, we can limit it. We need to systematically plant trees. Increasing forest cover reduces the impact of the main culprit on the greenhouse effect – H_2O. Forests bind water by limiting evaporation. The development of flora and fauna is also important, not to mention the tourism and recreational benefits as an important element of sustainable development. Coal-based energy should be developed and power plants should be equipped with modern dust removal equipment that significantly reduces SO_2 and NO_x emissions by 90-95%. Coal-fired power plants and combined heat and power plants are a valuable source of CO_2 for crops, multiplying their yields. The climate cycle is based on water, and in the absence of human intervention, the Earth itself maintains this cycle. Currently, humans, through far-reaching imagination, a result of which is sustainable development, can stimulate climate change, adapting it to their own needs and thus subduing the Earth. To achieve this, it is sufficient to reforest an appropriate percentage of the land surface. This is not difficult – given the current state of science, mathematical modeling of processes is capable of this task. However, there is concern that we may not make it in time and that global warming will continue despite our decisive but delayed corrective actions.

References

1. *Dwutlenek węgla uszkadza lód*, https://kopalniawiedzy.pl/dwutlenek-wegla-lod-lodowiec,16796, 12.10.2012.
2. *Globalne ocieplenie.* Wikipedia, https://pl.wikipedia.org/wiki/Zmiana_klimatu
3. Greenpeace (Marzec 2024). *Analiza skali wycinki w polskich lasach i rekomendacje Greenpeace, Materiał prasowy przygotowany przez Greenpeace Polska.*
4. http://ekoproblemy.webpark.pl
5. http://eomega.eu/odsiarczanie-gazow-spalinowych/#:~:text=Charakterystyka%20 instalacji%20odsiarczania%20spalin:%20*%20wysoka%20skuteczno%C5%9B%C4%87, pracowa%C4%87%20w%20szerokim%20zakresie%20zmienno%C5%9Bci%20strumieni a%20spalin.
6. https://1filter.pl/technika-filtrow-workowych/
7. https://polskiprzemysl.com.pl/wiadomosci-z-kraju-energetyka/instalacja-odazotowania-spalin/#:~:text=redukuje%20emisj%C4%99%20tlenk%C3%B3w%20azotu%20NOx%20 do%20atmosfery%2C,wymaga%C5%82%20szczeg%C3%B3%C5%82owych%20uzgodn ie%C5%84%20detali%20i%20zastosowania%20niekonwencjonalnych
8. https://upload.wikimedia.org/wikipedia/commons/b/b7/Solar_SpectrumPL.png
9. https://www.mokrosz.pl/odazotowanie-spalin/
10. Jarosiński, J. (1996). *Techniki czystego spalania.* Warszawa: WNT.
11. Jaworski, Z. (1998). Czy człowiek zmienia klimat. *Wiedza i Życie, 5*.
12. Komitet Naukowy ONZ (IPCC) (25.09.2020). *Ocean i kriosfera w zmieniającym się klimacie*. Monako.
13. Lewandowski, B., Klugman-Rodziemska, E. (2017). *Proekologiczne odnawialne źródła energii.* Warszawa: PWN.
14. Miłek, M. (2009). Efekt cieplarniany – CO2, Integracja gospodarcza w rozszerzonej UE: od wolnego handlu do unii walutowej , Pod red. J. Kundery, Wydział Prawa, Administracji i Ekonomii Uniwersytetu Wrocławskiego, Wrocław 2009r.
15. NASA publikuje pierwsze zdjęcia Wenus – Te odkrycia wprawiają naukowców w osłupienie!, https://www.youtube.com/watch?v=DfQBclQ8cIc .
16. Poudel, M., Dunn, B. (September 2023). *Greenhouse Carbon Dioxide Supplementation, Division of Agricultural Sciences and Natural Resources.* Oklahoma State University, Oklahoma Cooperative Extension Service, HLA-6723.
17. *Recykling papieru (makulatury)*, https://www.oostdam.pl/recykling-papieru-makulatury/
18. *Rocznik statystyczny leśnictwa GUS* (2019, 2023). Warszawa.
19. Synowiecki, Ł. (19.11.2024). Rządy się zmieniają, ale wycinka trwa. Pod topór idą stuletnie giganty. *Ochrona Lasów*, https://lasy.pracownia.org.pl/aktualnosci/550-rzady-sie-zmieniaja-ale-wycinka-trwa-pod-topor-ida-stuletnie-giganty

20. Wielka wycinka w Polsce trwa. *Dziennie wyjeżdża 6 tys. ciężarówek drewna, 11.04.2024,* https://www.bankier.pl/wiadomosc/Wielka-wycinka-w-Polsce-trwa-Dziennie-wyjezdza-6-tys-ciezarowek-drewna-8726480.html
21. *Wikimedia COMMONS*, https://commons.wikimedia.org/wiki/File:Zmiany_%C5%9Bredniej_temperatury_globalnej.svg
22. Wójcik, J. (2008). Bezpieczeństwo energetyczne. *Przegląd Organizacji, Nr 12*, pp. 28-32.
23. Wójcik, J. (2013). *Motivations and control in technical systems*. *Systems Supporting Production Engeneering.* Monograph. Gliwice, pp. 163-185.
24. Wójcik, J. (2011). Zarządzanie informacją przez systemy techniczne. *PSZW Studia i Materiały, nr 40.* Bydgoszcz, pp. 344-355.
25. WWF, https://www.wwf.pl/aktualnosci/ratunek-przed-susza-nie-deszcz-polityka-klimatyczna, 23.06.2020.
26. Zmiana klimatu 2013 (2016.01.10). Fizyczne podsumowanie naukowe, streszczenie dla decydentów. In: *Zmiana klimatu 2013: fizyczne podstawy naukowe. Przyczynek I Grupy Roboczej do piątego Raportu oceny zmiany klimatu Międzyrządowego Zespołu ds. Zmiany Klimatu* [on-line]. Międzyrządowy Zespół do spraw Zmian Klimatu.