GLOBAL CLIMATE CHANGE AND TEMPERATURE BALANCE: RISKS AND PROSPECTS

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Abstract

This paper focuses on global climate change and the balance of global temperatures. It has been established that CO_2 emissions and solar activity exert the greatest influence on changes in average temperatures.
The study explores the relationship between average temperature changes, the rate of solar energy input, CO_2 concentration, and cyclical periods. It was found that CO_2 emissions can be significantly reduced. The findings indicate that even with reductions and minimization of CO_2 emissions, such as on the European continent, the average temperature increase observed over the past 48–50 years will not decrease, and a return to the temperature levels of 100 years ago is not feasible. However, it is possible to project the stabilization of this increase at around 1.5°C.
Furthermore, this research highlights the critical link between CO_2 emissions, solar activity, and the broader natural and technological risks associated with climate change. These risks include extreme weather events, natural disasters, and impacts on industrial processes, underscoring the importance of innovative methodologies and practices for risk mitigation.

Keywords: climate change, CO_2 emissions, solar activity, temperature balance, sunspot activity, climate change, climate-related risks, and statistical model

I. Introduction

Climate change has a profound impact on people, the economy, and the environment. Extreme heat was recorded in 2023, leading to droughts and wildfires. In Europe, sea surface temperatures increased further, reaching record highs. Simultaneously, glaciers began to melt. The year 2023 was the warmest on record in Western and Southwestern European countries. The levels of carbon, nitrogen oxides, methane, and chlorofluorocarbons, which contribute to the greenhouse effect, are rapidly increasing due to emissions from industrial facilities and transportation. Consequently, the frequency of storms, blizzards, and floods has risen. According to the International Meteorological Organization (European Union Climate Change Program), the rate of warming in Europe has more than doubled compared to the global average since 1980. In 2023, the average temperature in Europe increased by 2.13°C. [1,2]. Climate change is one of the most significant challenges faced by scientists and engineers. A pressing scientific issue is whether the global rise in average temperatures could ever return to previous levels, what challenges and risks exist along this path, and what efforts will be required to achieve it. In other words, is it possible to achieve global climate equilibrium (temperature equilibrium)?

In light of the ongoing shifts in global energy strategies, particularly the transition from traditional fossil fuels to more sustainable chemical processes, it becomes increasingly important to consider the broader implications of these changes on climate dynamics. The evolution from “crude oil to chem” and emerging technologies like “carbon to chem” highlight how industrial innovations are responding to environmental pressures. These advancements underscore the necessity of integrating such forward-looking approaches into climate risk assessments, particularly when considering the potential impacts on CO_2 emissions and their role in global temperature regulation [3].The objective of this research is to investigate the emergence of global climate equilibrium. Atmospheric pollutants include greenhouse gases (GHGs) that block thermal radiation from the Earth while allowing heat from the Sun to reach the Earth's surface. Industrial greenhouse gases (IGHGs) refer to gases released into the atmosphere as a result of fuel combustion and other economic activities. The formation of IGHGs involves the following gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (CF_4, C_2F_6), halogenated hydrocarbons, sulfur hexafluoride (SF_6), and ammonia (NH_3). Additionally, indirect greenhouse gases, which are also pollutants, include nitrogen oxides (NOx) and other volatile organic compounds (VOCs).

The list of harmful substances polluting the atmosphere includes: carbon compounds (oxides); sulfur compounds (hydrogen sulfide, sulfur dioxide, and sulfur trioxide); nitrogen compounds (ammonia, nitrogen oxides, etc.); halogens (their chlorine, fluorine, bromine compounds, etc.); hydrocarbons (benzene, toluene, xylene); alcohols (methanol, ethanol, etc.); ethers; and aerosols of various origins—dust, smoke, and fog.These substances pollute the atmosphere both directly and through oxidation and conversion into other harmful compounds.The primary sources of atmospheric pollution are the metallurgical, cement, chemical, and petrochemical industries, thermal power plants, residential and industrial boilers, and transportation. Among these gases, carbon dioxide (CO_2 equivalent) was specifically mentioned in the study. Using this gas as an example, the study examines all gases contributing to the formation of the greenhouse effect [4-7].

It is well established that climate change is occurring and average temperatures are rising, as shown in Table 1. The primary factors influencing average temperature are the concentration of CO2 in the atmosphere (greenhouse effect) and solar activity. Other anomalous conditions may also arise during this time. Given these considerations, scientific research in this area is ongoing. Over the past 100 years, average temperature increases have been studied across different continents worldwide. Factors affecting the rise in average temperature have been identified, and statistical indicators have been used to analyze the annual average temperature increases across the continents of Europe, North and South America, Asia, Africa, and Oceania.

The factors most significantly influencing the rise in average global temperatures are primarily linked to human activities. These factors include:

1. Fossil fuel combustion:

- The burning of fossil fuels, such as coal, oil, and natural gas, releases large amounts of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere. These gases trap solar heat, leading to an increase in atmospheric temperatures.

2. Deforestation:

- Deforestation leads to the release of carbon into the atmosphere. Trees absorb carbon dioxide through photosynthesis, and a reduction in this process increases carbon levels in the atmosphere.

3. Industrial processes:

- Industrial activities, including metal production, cement manufacturing, and other processes, are significant sources of greenhouse gases.

4. Agricultural activities:

- Agricultural practices, particularly the raising of livestock and rice cultivation, are major sources of methane (CH_4) emissions. Methane is a very potent greenhouse gas, more effective than carbon dioxide.

5. Waste management:

- Methane and other greenhouse gases are released into the atmosphere due to improper waste handling and landfill operations.

6. Transportation:

- Vehicles such as cars, trucks, airplanes, and ships burn fossil fuels and emit greenhouse gases into the atmosphere.

7. Energy use:

- The production and use of electricity result in the emission of large quantities of greenhouse gases, especially when energy is generated from fossil fuels.

These factors are the primary contributors to the rise in average global temperatures. To combat climate change, it is essential to implement measures to manage and reduce these factors.

Heat (solar radiation) reaching Earth from the sun can vary depending on several factors. These changes can be short-term or long-term and are mainly associated with the following factors:

1. Solar activity:

- Solar activity changes in 11-year cycles. During these periods, the number of sunspots and the intensity of solar radiation fluctuate. When there are more sunspots, solar radiation slightly increases.

2. Earth's orbital parameters:

- These changes, known as Milankovitch cycles, are related to the eccentricity of Earth's orbit, axial tilt, and precession (the wobble of Earth's axis). These variations affect the amount of solar radiation reaching Earth over millennia and can lead to glacial periods.

3. Dust and aerosols in the atmosphere:

- Volcanic eruptions or large-scale wildfires release significant amounts of dust and aerosols into the atmosphere. These particles can block sunlight from reaching Earth's surface, causing a global cooling effect. For example, the eruption of Mount Pinatubo in 1991 led to a temporary decrease in global temperatures for several years.

4. Human activities:

- Aerosol emissions into the atmosphere from human activities (e.g., industrial processes and fuel combustion) can reflect solar radiation, but this effect is short-lived and does not fully offset the global warming effect caused by greenhouse gases.

5. The role of clouds:

- Clouds can both reflect and absorb solar radiation, altering the amount of solar energy that reaches Earth's surface. This cloud effect depends on the type, height, and density of the clouds.

6. Changes in Earth's albedo:

- The albedo of Earth's surface, or its ability to reflect sunlight, also affects how solar radiation is perceived. For example, snow and ice have a high albedo and reflect sunlight. As ice melts, darker surfaces (water and land) are exposed, absorbing more solar radiation and increasing temperatures.

The factors mentioned above determine the amount of heat that reaches Earth from the sun and its impact on the planet. Human activities, particularly the emission of greenhouse gases, disrupt Earth's energy balance and lead to global warming. While changes in solar radiation can cause short-term climate variations, the current trend of global warming is largely the result of human activity.

The statistical mathematical model was constructed based on statistical indicators using the example of the European continent. Climate change and its causes were studied through certain simplifications using these established statistical models. The average temperature increase from 1900 to 2023 was analyzed based on statistical data. A multifactorial experimental design matrix was developed using these indicators [8, 9]. The coded level values and the parameter variation intervals affecting the increase in average temperature, as determined by the coefficients, are described in Table 1.

Table 1: *Coded Levels and Parameter Variation Ranges Affecting the Increase in Average Temperature Across Factors*

Factor Names	Coded Levels			Variation Interval
	-1	0	+1	
X_1, CO_2 Concentration, ppm	1.4	2.3	3.2	0.9
X_2, Solar Activity, m/s	200	292	384	92
X_3, Duration, years	50	100	150	50

The multifactorial design matrix is presented in Table 2.

Table 2: *Multifactorial Design Matrix*

№	CO2 Concentration, ppm	Solar Activity, m/s	Duration, years	Output Parameter (Average Temperature),°C
1	1,4	200	50	0.1
2	1,4	200	50	0.2
3	1,4	200	50	0.3
4	1,4	292	100	0.4
5	1,4	292	100	0.5
6	1,4	292	100	0.6
7	1,4	384	150	0.7
8	1,4	384	150	0.8
9	1,4	384	150	0.9
10	2.3	200	100	1
11	2.3	200	100	1.1
12	2.3	200	100	1.2
13	2.3	292	150	1.3
14	2.3	292	150	1.4
15	2.3	292	150	1.5
16	2.3	384	50	1.6
17	2.3	384	50	1.7
18	2.3	384	50	1.82
19	4,6	200	150	1.84
20	4,6	200	150	1.86
21	4,6	200	150	1.88
22	4,6	292	50	1.9
23	4,6	292	50	1.95
24	4,6	292	50	1.98
25	4,6	384	100	2
26	4,6	384	100	2.1
27	4,6	384	100	2.15

Table 2 presents the results of the average annual temperature calculations depending on various factors. As a result, the following regression equation was obtained using the formula (2):

$$Y = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{\substack{i.j=1 \\ i \neq j}}^{n} b_{ij} x_i x_j + \sum_{i=1}^{n} b_{ii} x_i^2 \quad (1)$$

Here, x_i – represents the factors in the climate change process; n - is the number of factor, *bi, bij, bii* - the coefficients in the regression equation represent linear, interaction, and quadratic effects, respectively. In this study, the number of factors is 3. The regression coefficients are determined using the following well-known formula:

$$b_i = \frac{\partial f}{\partial x_i};\ b_{ij} = \frac{\partial^2 f}{\partial x_i \partial x_j};\ b_{ii} = \frac{\partial^2 f}{2\partial {x_i}^2} \quad (2)$$

$$Y_{temp} = 1.2881 - 0{,}7881 C_{CO_{2(1,4)}} + 0.01141 C_{CO_{2(2,3)}} + 0.6741 C_{CO_{2(4,6)}} - 0.2348 G_{a(200)} - 0.0070 G_{a(292)} + 0.2419 G_{a(384)} - 0.0048 P_{50} - 0.0604 P_{100} + 0.0652 P_{150} \quad (3)$$

Here, $C_{CO_2} - CO_2$ concentration, G_a - galactic solar activity, P – time (cycle period)

$$Y_{temp} = 17.333 - 0.305 x_3 - 0.96 x_1^2 - 0.757 x_2^2 - 0.486 x_3^2 \quad (4)$$

$$Y_{temp} = 13.4259 - 0.3204 C_{co_{2(1,4)}} - 0.0370 C_{co_{2(2,3)}} + 0.3574 C_{co_{2(3,2)}} - 0.1859 G_{a(200)} + 0.0263 G_{a(292)} + 0.1596 G_{a(384)} - 0.0470 P_{10} + 0.0763 P_{60} - 0.0293 P_{110} \quad (5)$$

$$Y_{temp} = 15{,}4000 - 0{,}7444 C_{co_{2(1,4)}} - 0.1444 C_{co_{2(2,3)}} + 0.8889 C_{co_{2(3,2)}} - 0.1644 G_{a(200)} + 0.0089 G_{a(292)} + 0.1556 G_{a(384)} + 0.1800 P_0 - 0.0133 P_{50} - 0.1667 P_{100} \quad (6)$$

Equations (3) and (4) represent linear and nonlinear regression models of the change in average temperature over 100 years on the European continent. Equations (5) and (6) are regression models of the average temperature on the European continent as it stands now and 100 years ago [9].

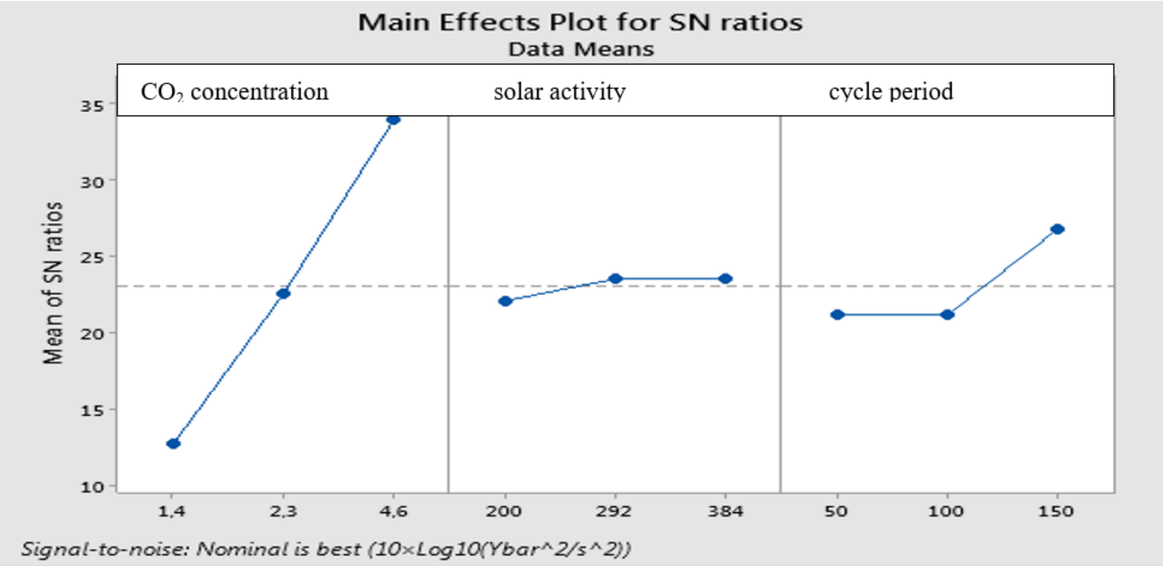

Figure 1: *Relationship between the increase in ambient temperature and CO_2 concentration, solar energy input rate (solar activity), and cycle period*

Processes in the environment, including continental temperatures, change according to nonlinear patterns [10, 11]. It is known from synergetic that nonlinear systems can be characterized by minimal energy dissipation [8]. Most natural processes are studied as nonlinear processes. Chaotic temperature fluctuations require the use of random functions. The method of E. Lorenz can be applied for the analysis of random functions [12, 13]. During this time, unstable harmonic oscillations (peaks) are separated, and the effects of other oscillations are ignored for simplicity.

$$\frac{dx}{d\tau} = k \cdot (y - x) \tag{7}$$

$$\frac{dy}{d\tau} = -x \cdot z + r \cdot x - y \tag{8}$$

$$\frac{dz}{d\tau} = x \cdot y - b \cdot z \tag{9}$$

Here, r = R, R - Rayleigh number, k - Prandtl number, b - constants

Preliminary calculations indicated that linear regression models, in comparison to nonlinear regression models, demonstrate certain minor inaccuracies. These inaccuracies are partially mitigated through the application of nonlinear regression. The relationships between atmospheric temperature, CO_2 concentration, and solar activity across different continents were analyzed. Earth's ecological systems are inherently complex, interconnected, and self-regulating. Addressing the challenges posed by these systems necessitates consideration of their intrinsic natural laws, suggesting that the study of complex ecological systems is fundamentally reliant on experimental calculations.

Research Results and Analysis

The results of the computational experiment examining the relationship between changes in ambient temperature, CO_2 emissions, and the period (time) of solar energy input, as the output parameter, are presented in Figure 1. The impact of all three factors on the outcome, as well as their interaction effects, was analyzed using the statistical software packages "Minitab" and "Origin" based on the obtained statistical data. An increase in CO_2 concentration led to a rise in ambient temperature. The temperature increased as solar activity intensified and then remained constant. Over a 50-year period, the temperature changed little when the CO_2 concentration remained constant. In the following 50 years, the temperature increased. Figure 2 shows a normal probability plot. Figure 3 presents a contour plot of temperature dependence on the rate of solar energy input and the cycle period. The figure shows that temperature significantly varies depending on solar activity and the time of year. Figure 4 illustrates the relationship between temperature and CO_2 concentration over time. In this case, CO_2 concentration and the cycle period greatly influence the temperature. Figure 5 depicts the relationship between temperature, CO_2 concentration, and solar activity. The figure shows that as CO_2 concentration and solar energy increase, the temperature change also increases significantly. During the study, CO_2 concentration was identified as the most harmful gas released into the environment. However, other gas emissions also have consequences. Figure 6 shows bubble charts of temperature changes. The images indicate that CO_2 concentration and solar activity have the most significant impact on temperature change [14, 15]. Here, synergistic processes become more pronounced.

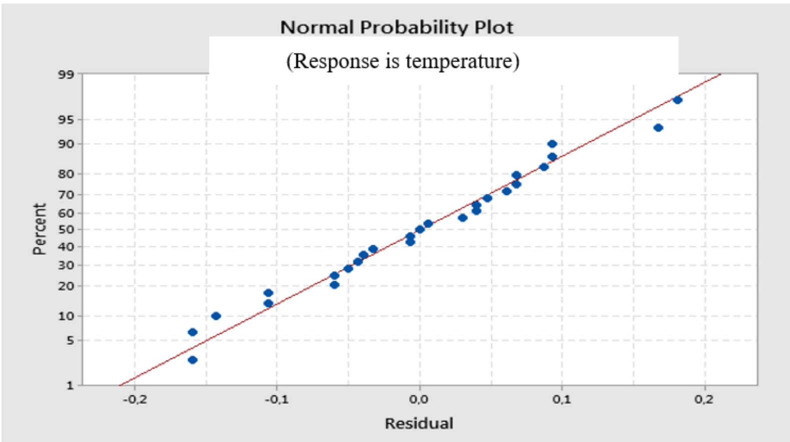

Figure 2: *Normal Probability Plot*

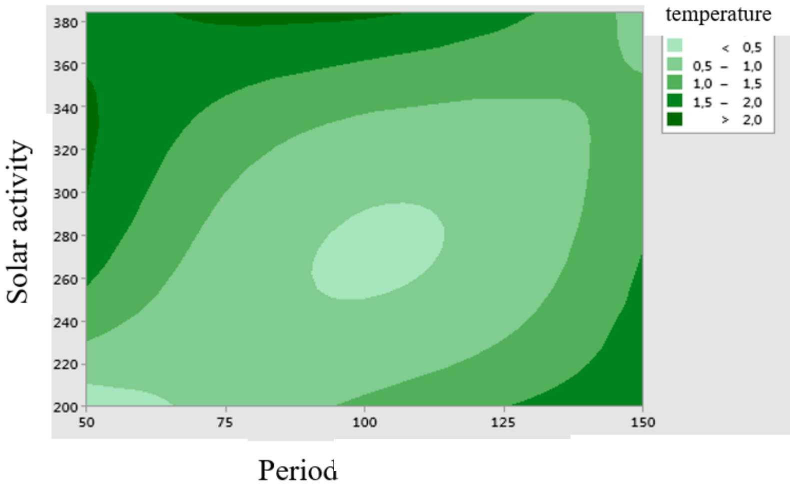

Figure 3: *Temperature Dependence on Solar Energy and Cycle Period*

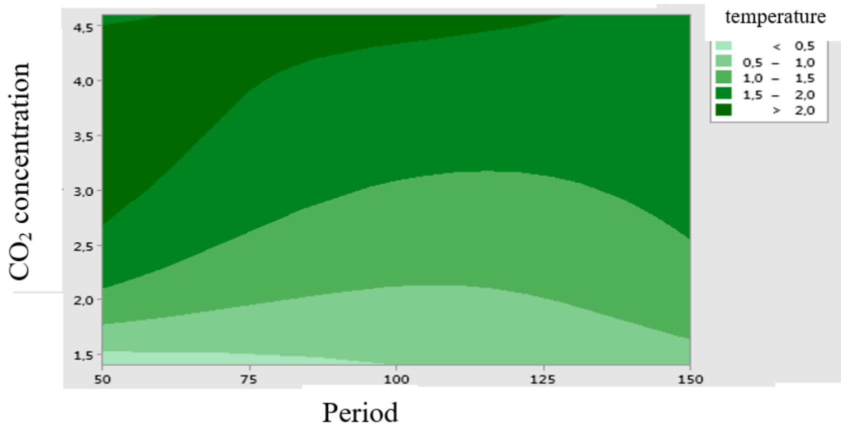

Figure 4: *Temperature Dependence on* CO_2 *Concentration and Period*

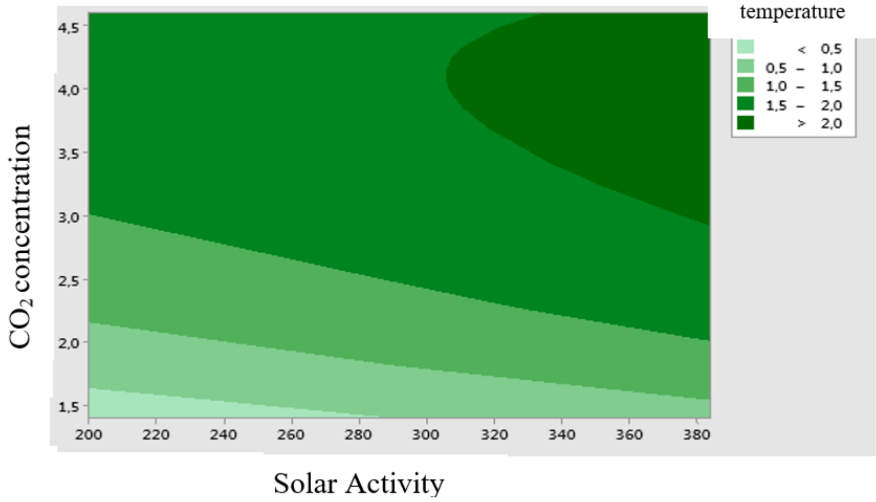

Figure 5: *Temperature Dependence on* CO_2 *Concentration and Solar Activity*

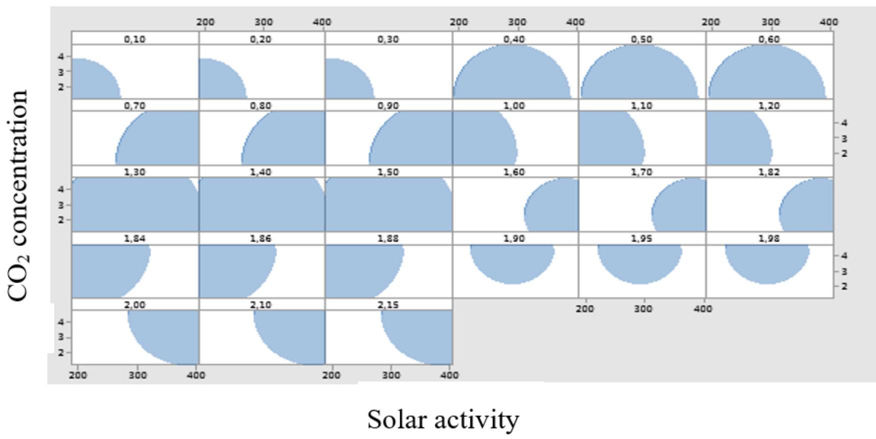

Figure 6: *Bubble Chart of Temperature Changes Depending on* CO_2 *Concentration and Solar Activity*

Environmental protection from harmful and hazardous industrial and transportation emissions is one of humanity's global challenges. Currently, scientists and engineers face the critical issue of preventing the pollution of the biosphere by CO_2 and other substances. Under these circumstances, it is necessary to develop a methodology for calculating harmful gases, including CO_2, emitted into the environment. The Department of Chemical Technology, Processing, and Ecology at Azerbaijan Technical University has developed a new methodology (using Python software) for calculating the quantity of harmful gases released into the atmosphere. Figure 7 shows the relationship between surface area temperature and solar activity and period. The figure reveals that the temperature variation is complex and has a specific volume depending on the cycle period and solar activity. Figure 8 illustrates the relationship between temperature variation area and CO_2 concentration and cycle period. The figure shows that the surface area does not have a complex structure but rather a convex surface. Figure 9 also shows the relationship between surface temperature variation, solar activity, and CO_2 concentration. In this case, the surface is convex and does not have a specific volume. Figures 7-9 demonstrate that temperature variation is highly dependent on the mentioned factors. However, as shown in Figure 7, the temperature variation surface has a specific volume depending on the cycle period and solar activity. This indicates that the relationship is complex and nonlinear.

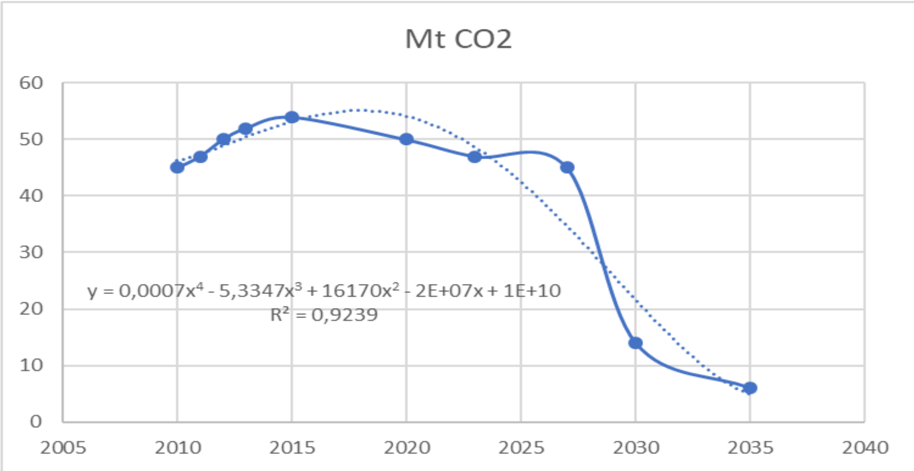

Figure 7: *Emissions from Fuel Combustion (million tons of CO_2 equivalent)*

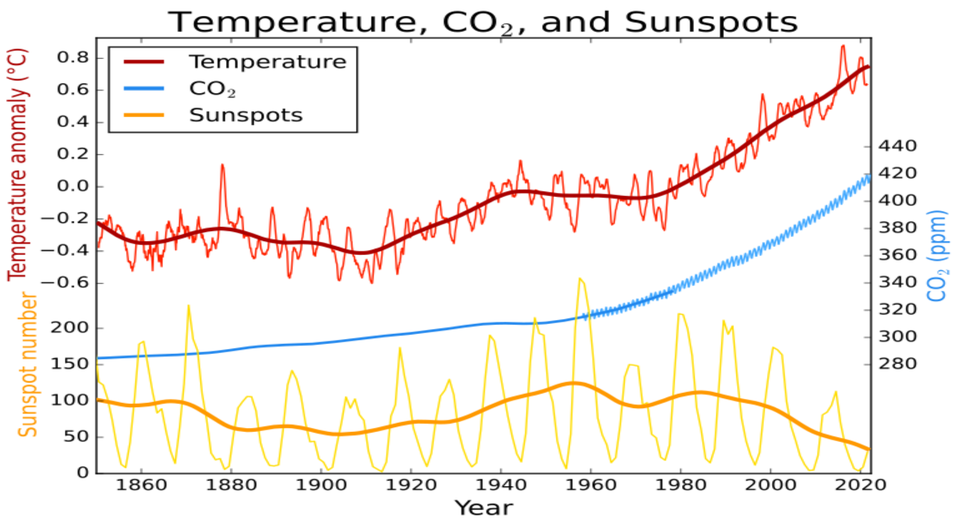

Figure 8: *Atmospheric CO_2, Average Surface Temperature, and Solar Activity (Sunspot Count) since 1850 [12]*

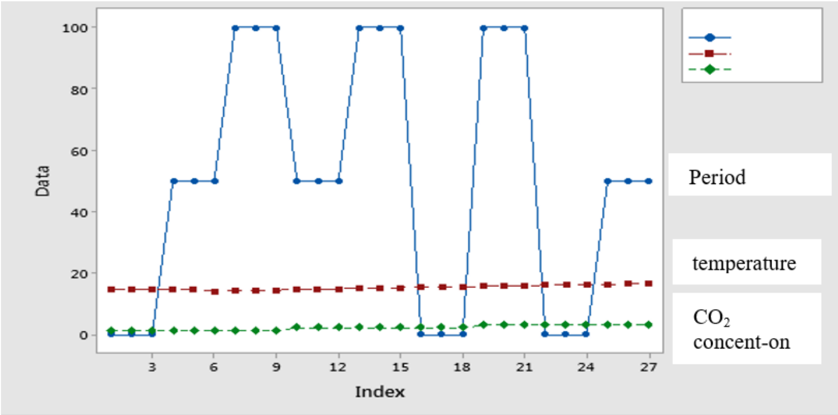

Figure 9: *Emergence of Temperature Equilibrium*

Results

CO_2 emissions and solar activity exert the greatest influence on global temperature changes. While humans cannot interfere with the Sun's activity, substantial reductions in CO_2, methane, and other IGHG emissions are possible. Other effects also depend on these two factors. Climate change is an extremely complex process, and there is a degree of randomness involved. The increase in CO_2 emissions is directly linked to human activities, including industrialization, wars, and other factors.

From the obtained graphs and calculations, it is evident that by reducing and minimizing CO_2 emissions, it is possible to forecast a likelihood of temperature reduction over the past 48-50 years and a return to the baseline temperature observed 100 years ago. However, this outcome underscores the broader principle that the more damage humanity causes to nature, the more severe the environmental consequences become.

Over the past 100 years, the Earth's average temperature has risen significantly. This increase is primarily attributed to the emissions of greenhouse gases (CO_2, CH_4, and others) resulting from human activities. Climate change has led to numerous severe consequences, including global warming, desertification, glacier melting, sea level rise, the destruction of small islands, and an increase in extreme weather events. The risk of progressive degradation of the global ecological system continues to grow.

Restoring the Earth's average temperature to its previous state is quite challenging and depends on several factors:

1. Reduction of greenhouse gas emissions: First and foremost, it is essential to significantly reduce the concentration of greenhouse gases in the atmosphere. This requires a rapid decrease in global carbon emissions and the implementation of technologies and policies aimed at removing greater amounts of carbon from the atmosphere.

2. Technological Innovations: Carbon capture and storage (CCS) technologies, methods for removing carbon from the atmosphere, and the widespread adoption of alternative energy sources are crucial.

3. Protection and Restoration of Natural Ecosystems: Natural methods, such as forest conservation, reforestation, and enhancing the carbon capture capacity of soil and oceans, also play a critical role.

4. Global Policy and Cooperation: Combating climate change requires global cooperation. Under international agreements like the United Nations Framework Convention on Climate Change (UNFCCC), the Paris Agreement, the Katowice Climate Package, and the Glasgow Climate Pact, it is crucial for countries to work together, adhere to their targets, and take significant steps in this direction.

Given these factors, the implementation of long-term strategies and systematic efforts is essential to attempt the restoration of global average temperatures to their historical norms. However, climatologists caution that some impacts may already be irreversible. At best, global warming might be limited and eventually halted, but achieving a full return to previous temperature levels will be an arduous, protracted, and costly endeavor.

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