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Economic assessment of the damage change on climate: Climate change and game theory

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Abstract

Climate change poses a very serious threat not only to the planet's population and biodiversity but also to the global economy, which is causing enormous economic damage. Therefore, the purpose of the article is to analyze and assess the extent of the damage caused to the economy in the context of climate change, using various expert assessments as well as the method of game theory. Combining various expert assessments shows that climate change has a long-term negative impact on global economic growth, labor productivity, and mass migration. The article analyzes several forecasting models. The results show that the planet is dangerously close to a turning point in climate change, and the models' consensus is that they agree that the economic damage from warming to 2°C will be negligible, but a 4°C warming would be disastrous for the economy. Additionally, the issue of achieving global cooperation to reduce greenhouse gas emissions was presented in game theory. The results show that the players did not choose the Nash equilibrium point but decided to what extent they would reduce their emissions.

Keywords: Ecological problem, Economic risk, Forecasting models, Game theory, GDP, Global warming, Matrix, Nash equilibrium.

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1. Introduction

Due to climate change, and especially global warming, an increase in the average temperature of the atmosphere leads to problems such as rising sea levels, food and water shortages, and increased heat stress on the working population. The latter can cause an escalation of existing and new conflicts, financial instability, poverty, and polarization of the population.

According to expert estimates, with the current workload of the world's population, as a result of existing economic and industrial growth, increased consumption, as well as increased emissions, global warming will be recorded by another $2\text{-}4^0$

C and an increase in ocean level by about 90 cm, which for very densely populated coastal areas and low-lying islands means a risk of displacement.

As a result, by 2050, about 140 million people will be forced to leave their homes, and 216 million people will lose their habitat [1] unless joint measures are taken. A sharp increase in global temperatures will eventually lead to some areas of the world becoming uninhabitable, which will result in an increase in migration levels.

The changes taking place both in the world's oceans, on land, and in the air create serious security problems not only from the perspective of the security of the biosphere but also lead to political, economic, social, demographic, and other consequences.

For this reason, it is appropriate to show the extent of the economic damage caused by climate change and also to present the process of decision-making by countries aimed at reducing emissions.

2. Literature Review

In the aftermath of the Cold War two decades ago, numerous policy statements and academic analyses suggested that various forms of environmental change were threats to global security. Environmental security discussions are now evolving into climate security discussions as the focus shifts to global warming and the effects it may have in the coming decades [2]. The description of the "conflict" between climate change and the economy is not new in the scientific community. Glanema et al. have shown that Global projections of macroeconomic climate change damages typically consider impacts from average annual and national temperatures over long time horizons [3]. Investigated the extent of regional damage caused by temperature and precipitation, including diurnal variability and extreme events. In their work, they also showed that the recorded losses are predicted for all regions, with the exception of those located in higher latitudes, where a decrease in temperature variability is beneficial [4, 5]. The biggest losses were incurred at lower latitudes in regions with lower cumulative historical emissions and lower current incomes.

Projections of the macroeconomic damage caused by future climate change are crucial to informing public and policy debates about adaptation [6] mitigation and climate justice. On the one hand, adaptation to climate impacts must be justified and planned based on an understanding of their future magnitude and spatial distribution. This is also important in the context of climate justice [7] as well as to key societal actors, including governments, central banks and private businesses, which increasingly require the inclusion of climate risks in their macroeconomic forecasts to aid adaptive decision-making [8]. On the other hand, climate mitigation policies such as the Paris Climate Agreement are often evaluated by balancing the costs of their implementation against the benefits of avoiding projected physical damages. Drouet et al. [9] have shown this evaluation occurs both formally through cost–benefit analyses, as well as with various forecasting models [9].

Markowitz and Shariff [10] they thought that projections of future damages meet challenges when informing these debates, in particular the human biases relating to uncertainty and remoteness that are raised by long-term perspectives, however Markowitz and Shariff [10] and Riahi et al. [11] were able to evaluate in their work assessing the extent of economic damages from climate change to which the world is already committed by historical emissions and socio-economic inertia (the range of future emission scenarios that are considered socio-economically plausible) [11].

A key reason why achieving international cooperation to address climate change is difficult is that there are strong free-rider incentives. The Osborne [12] showed that these incentives arise because climate change mitigation is a global public good – everyone benefits from there being less global warming, and everyone has an incentive for someone else to take on the burden of emission reductions [12]. This is compounded by the fact that because of sovereignty issues, international institutions are weak compared to national ones. Game theory which analyses the mathematics of strategic behaviour, Kutasi [13] showed thatcan help us obtain a better understanding of how the incentive to free-ride works, identify the potential barriers to cooperation, and find approaches to facilitate a cooperative outcome [13]. This paper surveys the game theoretic literature that relates to climate change, with an emphasis on approaches that try to find ways to facilitate cooperation. According to Piraveenan [14] Game theory is often applied by assuming that the game is given, and used to predict the behaviour of participants [14]. But an area of game theory known as implementation theory treats the desired outcome as given, and asks how to design a process that leads to this outcome.

The purpose of the article is to analyze and assess the extent of damage caused to the economy in the context of climate change.

3. Research Methodology

3.1. Potential Economic Damage

In the 20th century, in the early stages of the development of scientific progress, human attitudes towards the environment began to alter gradually and became more rational and conservative. One of the reasons was that in parallel to the development of public relations, humans began to exploit nature and natural resources, and environmental protection issues became crucial due to the shortage of energy resources and raw materials, environmental disorder, and deterioration in the quality of the environment as a result of the extirpation of certain species of animals and plants. This means that should humans not undertake measures to prevent environmental pollution, the existing environmental crisis could have turned into an ecological catastrophe. Human impact on the environment had its own manifestations of development. Particularly, the environment functioned based on the development of general laws of "natural self-organization." At present, the environment begins to change due to the development of the biosphere, which has been gradually losing its "naturalness" over the years. At the same time, environmental pollution primarily affects human health, causing many pathogenic diseases and worsening the ordinary functioning of the human body.

In the 21st century, the development of public relations and the application of modern technologies in substance had to contribute to the protection and improvement of human health; however, they also gave rise to new diseases that led to a decline in human life expectancy. In the studies and analyses conducted by various international and local organizations, factors affecting the protection and improvement of human health were identified. The obvious impact of environmental changes on human health led to the emergence of a new science called ecology, one of its most important directions of which is ecological formation. People all over the world are facing the reality of climate change – in many parts of the world, this is manifesting in an increased volatility of extreme weather events. Between 2000 and 2019, over 475,000 people lost their lives worldwide, and losses amounted to US$ 2.56 trillion.

Basic scenarios include significant risk that the global climate will change dramatically by the end of the current century. According to the forecasts of the Intergovernmental Panel on Climate Change [15] in the absence of policy measures to control emissions, global temperatures by 2100 will rise on average by 2.8° Celsius (at the best estimate in the range from 1.8° Celsius to 4° Celsius according to all the scenarios presented in the "Special Report on Emission Scenarios"). The probability of a further temperature increase is not negligible.

In the work of Stern [16], it is indicated that centenary GHG concentrations within the base scenario are stabilized at a level of no less than 750 parts per million hydrocarbon equivalent, as assumed in the last ones.

Uncertainty about the damage caused by climate change comes from various sources. First, scientific knowledge about the physical and ecological processes underlying climate change continues to develop. For example, it is not clear how quickly greenhouse gases will accumulate in the atmosphere, how sensitive the climate is to biological systems will increase the concentration of these gases, and where the "possible frontiers" will be, after which catastrophic climatic consequences will occur, such as the melting of the western ice cap in Antarctica or eternal permafrost, changing the character of monsoons, or turning the thermohaline circulation in the Atlantic Ocean.

Secondly, it is difficult to estimate how well people will be able to adapt to new climatic conditions. Thirdly, it is challenging to provide a current cost estimate of the damage that will be suffered by future generations.

In terms of economic mechanisms of environmental management, it is also necessary to consider the nature-oriented adjustment of economic development indicators, which subsequently can provide an opportunity to increase the competitiveness of environmental projects in the context of economic decision-making. This should be perceived from the following perspectives:

1. Overutilization of forest, water, land, biodiversity and natural resources in monetary terms (FWLBNR) is deducted from gross domestic product (GDP).

$$\mathrm{GDP} - \mathrm{FWLBNR} = \mathrm{GDP1} \quad (1)$$

2. Afterwards, loss in monetary terms arising from pollution of land and water areas, utilization of commodities hazardous for the environment and allotting of waste (FWLBNR) is deducted from the resultant GDP_1.

$$\mathrm{GDP1} - \mathrm{FWLBNR} = \mathrm{GDP2} \quad (2)$$

This adjustment allows for the comparison of economic growth indicators of various countries, taking into account the environmental factor, which makes it possible to realistically assess the indicators of economic growth of the countries. For example, in developing countries, indicators of economic growth become negative as a result of nature-oriented adjustments, evidencing that they are based on the overutilization of natural resources and environmental pollution. When defining rates of nature protection and nature utilization payments, it is necessary to consider all those factors that involve the utilization of natural resources and environmental pollution. Assessment methods are quite diverse and are summarized in Table 1.

Table 1.
Assessment methods of the utilization of natural resources and environmental pollution.

Method	Activity
Market price method	In case of direct utilization
Loss compensation method	In case of indirect utilization, erosion, pollution control, water conservation and in other cases
Travel cost method	Recreation and tourism
Hedonistic pricing method	Certain aspects of indirect utilization, future utilization (for example, an apartment in an ecologically favorable area)
Provisional (public) assessment method	Tourism and goods having no market price (the public itself decides how much it is willing to pay for that resource)
Public choice method	For all water and swamp goods and services
Income transfer method	For the services to use the ecosystems
Productivity method	Land, water, humidity level in the air, etc.

3.2. Forecasting Models for Assessing Economic Damage from Climate Change

Climate change will primarily affect global economic growth, labor productivity and mass migration, and frequent changes in extreme weather events can lead to the loss of property and infrastructure (Hurricane Sandy, which flooded most of New York in 2012, is a prime example of the significant loss of property and infrastructure).

According to the handbook for 2023-2024, published by the World Economic Forum, the categories of global risks that are most likely to lead to a global crisis were presented.

It is noteworthy that, according to the above handbook, 4 out of 10 of the risks presented relate to environmental risks (Figure 1), which once again requires warning in order to take targeted measures.

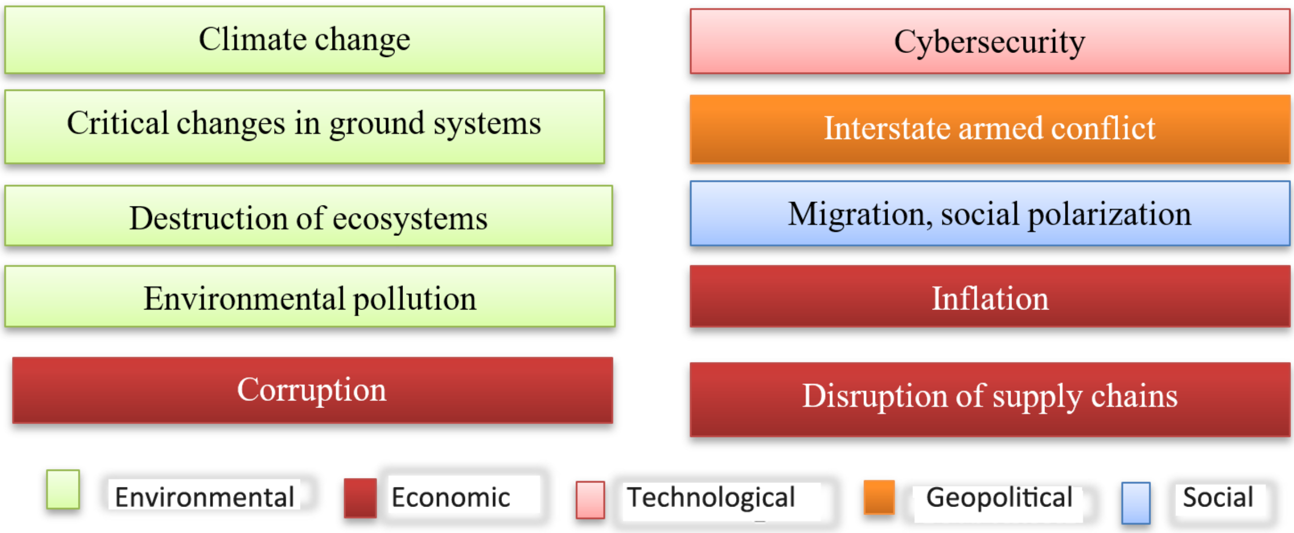


Figure 1.
Global risk categories for 2034 [17].

It should be noted that more frequent droughts can reduce yields, so food shortages will lead to an increase in world food prices and a reduction in consumer incomes. Moreover, a sharp increase in global temperatures will lead to the fact that some areas of the world will become uninhabitable:

In fact, the demand for an ever-decreasing amount of land will grow, and the population will have to live in a more concentrated area.

High energy costs will also lead to inflation. As our climate changes, we will consume a lot of energy both to heat our workplaces and living spaces in winter and to cool them in summer. Considering that energy forms the basis of most of the world's production, the secondary effects of rising energy prices on inflation will be felt by the economies of all states.

Most likely, insurance companies will bear most of the risk of global warming. Rising insurance costs increase inflation; moreover, insurance companies may refuse to provide insurance coverage to the population, which can create a serious problem for the country's public administration system and the state budget. They will have to increase social spending items to reduce insurance risks.

In addressing the challenges posed by climate change, the issue of food security is of paramount importance. This is the most important factor for agriculture, as this sector is directly related to the environment.

According to forecasts, economic losses from heat stress will amount to about $ 2,400 billion [18]. Heat stress is the cause of a decrease in labor productivity; in particular, in 2030, a 3.8% decrease in labor productivity is projected due to global warming. At the same time, the loss of working hours due to heat stress will exacerbate the problem of food security in many countries. If the temperature rises by 3°C, 400 million people will suffer from food shortages [18] and if the temperature rises by 3.5°C, global food supply chains will be disrupted.

Climate change will obviously also exacerbate the shortage of drinking water. Today, 12 of the 17 countries with the greatest water scarcity are located in the Middle East and North Africa. Increasing the duration and frequency of even minor droughts in this dry and hot region will further complicate the situation [19]. Economic losses from water shortages related to climate change will amount to between 6% and 14% of GDP by 2050 [20] and by 2030, about 3.9 billion people will experience water stress [17] by 2050 2/3 of the world's population will experience it [21, 22].

This rivalry, in turn, will provoke regional conflicts and migration. The number of people suffering from water shortages will increase from 3.6 billion to more than 5 billion people [23].

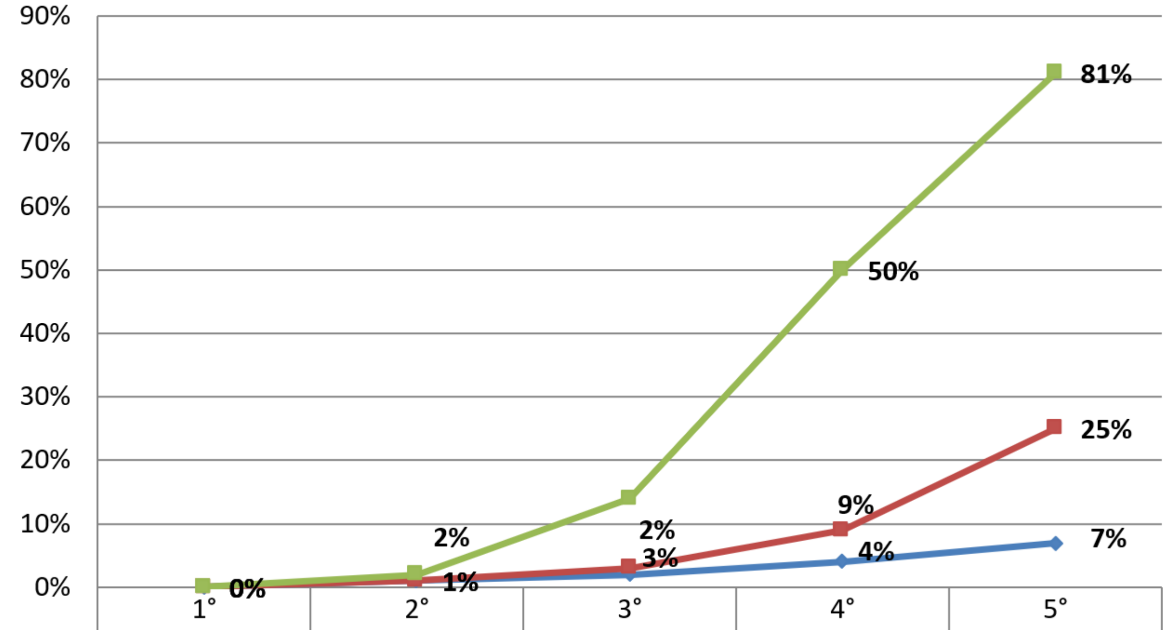
The impact of climate change on public health. The 2020 coronavirus pandemic seems to have nullified the threat of climate change, but there were positive aspects to this crisis. The COVID-19 pandemic has awakened people and shown how unstable and dangerous the world they live in is. The risks threatening the existence of mankind have become more visible, so people have become more aware that climate change is one of these risks [24].

However, today 7 million people worldwide die every year due to air pollution caused by climate change. It is predicted that in the period from 2030 to 2050, climate change will cause about 250,000 additional deaths per year from malnutrition, malaria, diarrhea, and heat stress [25]. Climate change will exacerbate existing inequalities by widening the gap between rich and poor people living in poverty [26]. More than 100 million people in developing countries will fall below the established poverty threshold [27].

The results of the forecasts made once again confirm the inevitable economic losses and increased costs as a result of climate change.

Various expert assessments show that irreversible climate change has a long-term negative impact on economic growth. Early estimates of the impact of global warming on global GDP appeared in the early 1990s, and since then, a number of studies have been conducted that matched the initial estimates. Estimates of economic damage from climate change presented differ depending on whether or not there is a tipping point at which damage to the economy accelerates. The study's baseline scenario assumes that once temperatures rise to 4°C, annual global economic activity will be reduced by 4% (Figure 2).

Nordhaus's model is widely used by economists and predicts the least worst-case scenario of the three models [28]. According to Nordhaus, the economic damage from climate change will be gradual, without a tipping point, and the earth's population will have long enough to offset any negative effects of global warming. Nordhaus estimates that the effects of climate change on the global economy are likely to be negligible over the next two decades.



	1°	2°	3°	4°	5°
Nordhaus	0%	1%	2%	4%	7%
Weitzman	0%	1%	3%	9%	25%
Dietz&Stern	0%	2%	14%	50%	81%

Figure 2.
Economic damage assessment models due to climate change [29].

Unlike the Nordhaus model, Weitzman's estimates are not so optimistic. Weitzman estimates that once temperatures reach 4°C [30], annual economic activity will be reduced by 9%. Under this scenario, insurance companies, agriculture and forestry are likely to suffer.

The Dietz and Stern [31] model, which estimates the economic damage caused by climate change, provides a worst-case scenario in which the global economy will suffer significant losses. Under that scenario, once temperatures reach 4°C, annual economic activity will be reduced by 50% (Figure 2). To put that into perspective, the Dietz and Stern [31] model predicts that if temperatures reach 4°C in 2080, the projected 3% annual economic growth rate will drop to 1.9% [31].

In addition to the above models, an example of an approach to assessing the economic consequences of climate change is also the studies of a number of reputable Australian scientists, who modeled the effects of global warming on real GDP for all regions between 1°C and 4°C. According to their estimation, in the first scenario, if the global temperature rises by 3°C compared to the pre-industrial period, the possible losses of the world economy in 2100 will amount to 9,593.71 billion dollars, which is approximately 3% of the world's gross product. In the second scenario, if the temperature rises by 4°C, the economic losses will amount to 23,149.18 billion dollars.

Moreover, studies by Australian scientists show that the economic damage caused by global warming fluctuates over time, showing an increasing trend and most states will face it in the long run [32]. For example, if the global temperature rises by 3°C, the GDP of Finland will decrease by 1.02%, Germany by 1.92%, Sweden by 2.67%, Nigeria by 3.56%, Great Britain by 3.97%, Malaysia by 4.12%, China by 4.35%, France by 5.82%, Indonesia by 7.51%, Russia by 8.93%, India by 9.90%, the USA by 10.52%, Japan by 10.70%, Canada by 13.08%, Armenia by 6.03%, and Azerbaijan by 1.80%.

Considering the three models, we can note that the temperature of 4°C can be considered a crucial phase of global warming; it is this temperature that is called the turning point at which the pace of global economic growth will decrease significantly.

3.3. Climate Change and Game Theory

Definition: The normal form representation of a game specifies.

1. The set of players in the game (in the context of climate change, these will often be countries), N.
2. A set S of strategy combinations, each strategy combination assigns a strategy to each player.
3. and the set of payoffs $\Pi = \{\pi i: i \in N\}$ received by each player for each possible strategy combination. Each payoff πi assigns a real number (the utility, It is possible to define strategic games more generally in terms of a preference relation for

each player on the set of strategy combinations It follows from ordinal utility theory that if a preference relation satisfies certain axioms, then it is representable by a utility function) [12] to a trategy combination.

The normal form representation of a game is sometimes also known as the strategic form of a game. When we consider a player i and strategy combination s, we will often write s−i to denote the strategies of players other than i, and write s = (si, s−i) [33].

Example (The Prisoner's Dilemma). Game theory is often applied by assuming that the game is given and used to predict the behaviour of participants [34]. But an area of game theory known as implementation theory treats the desired outcome as given, and asks how to design a process that leads to this outcome [35]. An example of such a process could be the negotiations for an international environmental agreement. This approach may help us design processes that are more likely to lead to cooperative outcomes. Addressing the free-rider incentives associated with climate change mitigation requires that we find mechanisms to facilitate cooperation between states [36, 37]. One such approach is international treaty-making. In 1992, countries negotiated the United Nations Framework Convention on Climate Change (UNFCCC). Since then, countries have negotiated the Kyoto Protocol to the UNFCCC, which included emissions reduction commitments for some developed countries, known as Annex I countries. Countries have been engaging in further negotiations at conferences of the parties to the UNFCCC and meetings of the parties to the Kyoto Protocol.

The problem of achieving cooperation to reduce greenhouse gas emissions is related to the prisoner's dilemma. All countries are collectively better off if they reduce their emissions, but each country is individually better off if they continue to pollute (Table 2) illustrates a two-country (or two groups of countries) situation, where the dilemma is to pay the cost of mitigation and adaptation or not to do anything for lower carbon emissions. If a country chooses to mitigate and adapt, it must pay the cost (C). Depending on strategies, in a simplified version, if both players mitigate, there is no change in temperature, so the cost of damage is zero (T_0). If one of them does not act, then at least 1 Celsius warming happens, so some economic damage will be realized (T_1). If no one acts, more seriously, let us say, 4 Celsius warming occurs with bigger economic damage.

Table 2.
The matrix of player winnings [13].

	B Player	
A Player	Abate	Pollute
Abate	$(C+T_0);(C+T_0)$	$(C+T_1)$;(T_1)
Pollute	(T_1) ; $(C+T_1)$	(T_4) ; (T_4)

Note: C = cost of mitigation and adaptation, T_0 = no temperature change, zero damage, T_1 = damage caused by rising temperature by 1 Celsius, T_4 = damage caused by rising temperature by 4 Celsius, $T_4 > C$, $T_4 > T_1$.

The strategy pair (Pollute, Pollute) is a Nash equilibrium [38, 39] because given that the second player chooses Pollute, the first player is better off choosing Pollute than choosing Abate, and vice versa. None of the other strategy combinations are Nash equilibria because in each case, at least one player can improve their payoff by changing their strategy. The strategy pair (Abate, Abate) is known as the social optimum because the collective payoff (the sum of each player's payoffs) is maximized. For this example, the Nash equilibrium has a much lower collective payoff than the social optimum. Climate change is similar to a prisoner's dilemma, but countries don't just make a decision about whether to pollute or not; they make a decision about how much to reduce their emissions [23].

4. Conclusion

The purpose of the paper is to assess the extent of damage to the economy in the context of climate change. The results of the analysis show that projections of the economy's response to climate change may change depending on the elements discussed and the type of model used. Incorporating assumptions about the impact of adaptation measures into models, which will largely depend on the projected development of the latest technologies, may also affect conclusions about the extent of economic losses. However, although it is not possible to accurately determine the extent of economic losses from climate change, the possibility of its extremely negative global consequences is very high.

The results obtained once again confirm the inevitable economic losses and increased costs as a result of climate change. Consequently, states must have an environmentally sustainable and long-term development strategy that clearly identifies the necessary measures to develop an appropriate set of tools, mathematical models, and methods that will reveal the relationship between economic and environmental indicators. Further studies are planned to assess the deterioration of human health in the context of climate change.

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