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CLIMATE DAMAGE AND REPARATORY VALUE

DANO CLIMÁTICO E VALORAÇÃO REPARATÓRIA

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Abstract
This article is based on bibliographic research, using the analytical and exploratory method and a theoretical- qualitative and critical approach. The main objective is to explore the economic effects caused by climate change, with the specific objectives of clarifying what climate change is, establishing a historical correlation between the increase in global temperature and human action, and reflecting on research that analyzes the economic impacts of climate change. The research begins by clarifying what climate change, global warming, and greenhouse gases are. It then shows how human interference has been altering the climate over the last 150 years. Finally, it assesses the extent of climate damage and the reparation model under construction in the Brazilian legal scenario. Thus, the text verifies the dimension of the ecological and economic impact resulting from climate change, with a proposal for a scenario of reparatory obligations relating to obligations to do and to pay, which are cumulatively enforceable.

Keywords: Global Warming. Economic Impacts. Climate Change. Reparatory Valuation.

Resumo
Este artigo utiliza a pesquisa bibliográfica, por meio do método analítico e exploratório, com método teórico-qualitativo e crítico. O obje- tivo principal é explorar os efeitos econômicos provocados pelas mudanças climáticas, tendo como objetivos específicos esclarecer o que são mudanças climáticas, fazer a correlação his- tórica entre aumento de temperatura global e ação antrópica e refletir sobre pesquisas que analisam os impactos econômicos das mudan- ças climáticas. A pesquisa inicia esclarecendo o que são mudanças climáticas, aquecimento global e gases de efeito estufa (GEE). Em se- guida, mostra como a interferência antrópica vem alterando o clima nos últimos 150 anos. Por fim, avaliam-se a dimensão do dano cli- mático e o modelo reparatório em construção no cenário jurídico brasileiro. Assim, o texto verifica a dimensão de impacto ecológico e econômico derivado das mudanças climáticas, com proposição de um cenário de obrigações reparatórias relativas a obrigações de fazer e de pagamento, cumulativamente exigíveis.

Palavras-chave: *Aquecimento Global. Impactos Econômicos. Mudanças Climáticas. Valoração Reparatória.*

1 INTRODUCTION

The main theme of this article is climate change, its economic aspects and how the valuation of climate damage is established in the Brazilian legal system. The research analyzes what climate change consists of and, subsequently, how it economically affects the global community and the intervention of the Law. In order to do this, some impacts were verified more directly, such as the possible material and human damage due to increases in world temperatures caused by human beings in subsequent decades.

What are the economic impacts of climate change and how does the law deal with them? This will be the guiding question for this study, based on the realiza- tion that human beings are the cause of much of the current climate change, given that, until the 18th century, climate change was associated with natural events. The consequences of the rise in the Earth's temperature are numerous, and one of the factors that must be considered is the natural, material and, consequently, human damage. The verification of these elements may be able to direct public policies, as well as civil society and individuals, towards better decision-making in relation to the factors catalyzing climate change.

In this sense, this research, in finding that contemporary climate change is enhanced by anthropogenic activities, hypothesizes that this has been generating and will create serious economic consequences (natural, material, and human), making it possible to quantify current losses, in terms of countries' economic growth and predict severe future losses, such as the projected loss of life resulting from climate change.

The effects of climate change have been felt by all living beings and other entities on the planet Research conducted over the last few decades has provided strong evidence that human interference has accelerated these effects, resulting in an increase in the Earth's temperature (global warming) caused by numerous activities, particularly the burning of fossil fuels such as oil, coal, and natural gas, as well as deforestation and slash-and-burn practices.

Global warming is mainly evidenced by the increase in the global average temperature of the air and oceans, which causes sea and ocean levels to rise due to the melting of snow and ice in the polar ice caps.

Today, average global surface temperatures are the highest they have been in the last five centuries, and in the last 100 years the average global surface tem- perature has risen by around 0.74°C. If no measures are taken to slow down this global warming process, it is possible that, still in the 21st century, the global tem- perature will increase by an average of 2°C to 5.8°C. Such changes in the Earth's average temperature could have major impacts on all forms of life on the planet, including economic impacts.

It is therefore important to spark debate and promote an understanding that climate change must be treated as a fundamental issue for humanity in the 21st century. On the other hand, it is relevant to indicate how the valuation of climate damage is established in the Brazilian legal system, considering the significant increase in so-called climate litigation over the years.

The article is justified by the emergence of the subject of climate change and the important relationship between these changes and their economic impacts, as a way of demonstrating the harmful effects of human interference in the planet's climate and how the law has reacted to these implications.

The main objective is to point out some of the economic effects caused by climate change, with the specific objectives of clarifying what climate change is, establishing the historical correlation between the increase in global temperature and anthropogenic action, reflecting on research that analyzes the economic im- pacts of climate change and, finally, placing the Law as a fundamental element in mitigating climate change.

The text begins by explaining the meaning of climate change and related concepts such as global warming and greenhouse gases (GHG). The research shows, with graphical analysis, the correlations between the increase in world pop- ulation, the increase in world wealth, the increase in global CO_2 emissions into the atmosphere, the increase in the global concentration of CO_2 in the atmosphere, and the accelerated increase in global average temperature. This information is important because it relates to the Industrial Revolution, which took place 150 years ago and is an important milestone for understanding the period in which the planet finds itself.

Based on research and economic surveys, the text illustrates the impacts that climate change can have on the economy. The analytical-exploratory method was used to analyze and correlate databases from OurWorldinData.org and the IPCC. This allows the data to be explored, showing human interference in the planet's climate over the last 150 years.

The research seeks to illustrate the economic impacts of climate change by means of a bibliographical analysis, using a theoretical-qualitative and critical method, analyzing the relationship between climate change and the mortality re- sulting from these changes. Finally, it will address climate litigation and the role of law in proposing a scenario of reparatory actions related to obligations to perform and pay, which are cumulatively enforceable.

2 CLIMATE CHANGE AND ANTHROPOGENIC ACTIVITIES

Climate change means an alteration in the climate average or in the variabil- ity of its standard characteristics, which may remain for a long period of time, in decades, centuries or millennia (UNFCC, 2011). In the Brazilian legal system, the concept is attributed by Law no. 12.187/2009, whose Article 2, VIII, identifies climate change as a change in climate that can be directly or indirectly attributed to human activity that alters the composition of the world atmosphere and that is added to that caused by natural climate variability observed over comparable periods (Brasil, 2009). Related to climate change are its adverse effects, defined as changes in the physical environment or biota resulting from climate change that have significant deleterious effects on the composition, resilience, or productivity of natural and managed ecosystems, on the functioning of socio-economic sys- tems or on human health and well-being (Art. 2, II).

Throughout most of the history of planet Earth, changes have occurred as a result of natural factors. These elements are referred to as natural variability (of climate), which is generated by changes in climate systems and due to natural external causes. Paleoclimate records, which may contain traces dating thousands of years, and climate models show that temperatures have varied over time (Eyring et al., 2021).

Natural variability is characterized as internal and external. Internal variabil- ity occurs when there is a redistribution of energy in the climate system, such as changes in atmospheric circulation, which affect the day-to-day regional climate. On the other hand, external natural variability can occur as a result of changes in the Earth's orbit, due to variations in the way solar energy is received or through large volcanic eruptions. Despite having a major impact on the Earth's climate, natural variability has had little influence on climate in recent centuries (Eyring et al., 2021).

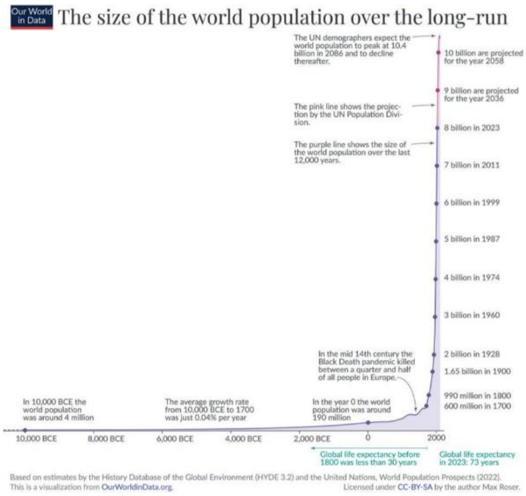
It should also be noted that natural variability has little impact if analyzed over decades or centuries, in the sense that, estimated over the period from 1850 to 2020, its contribution to global warming at the surface varied from −0.23°C to +0.23°C in the climate. Research using simulations[1] shows that natural variability has had little effect on the climate over a long period (Eyring et al., 2021).

So what has caused the drastic change in temperature over the last 150 years? To answer this question, it is important to look at some of the changes that have occurred over the centuries.

Graph 1 illustrates the world population from the year 10,000 BC to an expectation for the year 2086 AD.

Graph 1.

The size of the world population over the years.



Source: Mathieu and Rodés-Guirao (2022).

Graph 1 shows that: (a) in 10,000 BC, the world population was 4 million people; (b) in 1,700 AD, the world population was 600 million people; (c) be- tween 10,000 BC and 1,700 AD, the growth rate was 0.04% per year; (d) life expectancy up to the 19th

[1] Regarding climate models, it can be clarified that “climate models are important tools for understanding past, present and future climate change. They are sophisticated computer programs that are based on fundamental laws of physics of the atmosphere, ocean, ice, and land. Climate models perform their calculations on a three-dimensional grid made of small bricks or ‘gridcells’ of about 100 km across. Processes that occur on scales smaller than the model grid cells (such as the transformation of cloud moisture into rain) are treated in a simplified way. This simplification is done differently in different models. Some models include more processes and complexity than others; some represent processes in finer detail (smaller grid cells) than others. Hence the simulated climate and climate change vary between models. […] Models continue to improve and get better and better at simulating the large variety of important processes that affect climate. […] Scientists evaluate the performance of climate models by comparing historical climate model simulations to observations. This evaluation includes comparison of large-scale averages as well as more detailed regional and seasonal variations. There are two important aspects to consider: (i) how models perform individually and (ii) how they perform as a group. The average of many models often compares better against observations than any individual model, since errors in representing detailed processes tend to cancel each other out in multi-model averages.

century was 30 years; (e) over the past 220 years, the population has grown from 1 billion to 8 billion people; (f) it is expected that the world population will reach 9 billion in 2036 and 10 billion in 2058; (g) life expectancy in 2019 was 73 years; and (h) there is a projection that, in 2086, the world population will peak at 10.4 billion and begin to decline.

The exponential increase in the world's population began in the 18th cen- tury, which, not coincidentally, was the century of the Industrial Revolution[2]. As Galor (2023) points out, there is a reciprocal relationship between population size and technological change. However, if until the 18th century, population grew in line with technological progress, as proposed by Thomas Malthus[3], the Industrial Revolution broke this cycle. The Revolution, which occurred due to significant technological advances, led to an increase in life expectancy, since the surplus of production over the following decades was able to improve the lives of individuals, with more technological advances and greater access for individuals, even though inequality became a problem in the centuries to come.

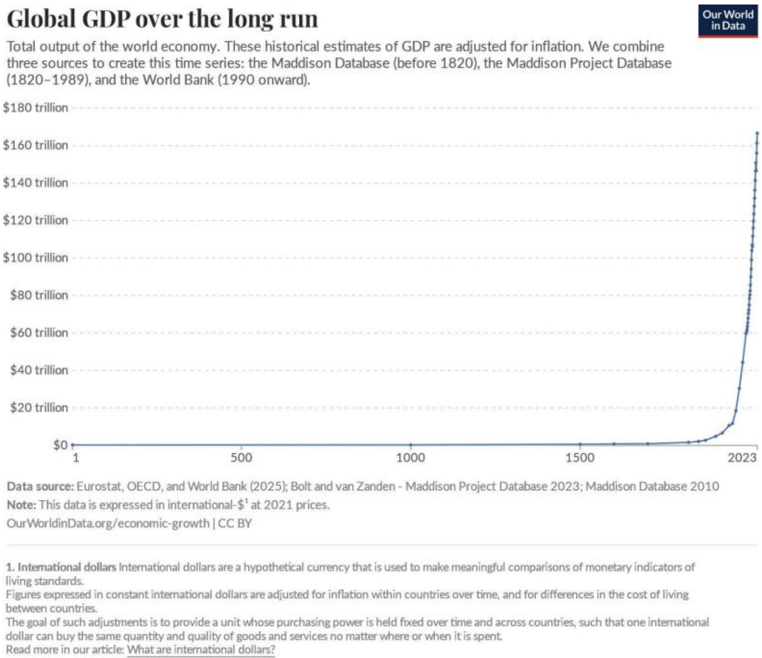
The increase in world population, in turn, led to an increase in world pro- duction (Graph 2).

[2] According to Galor (2023, p. 75): "The steam engine, designed by the British ironmonger Thomas Newcomen, entered commercial use in 1712. It had a fairly simple and banal purpose: to pump water out of coal mines – a complex task that demanded a significant workforce back in the eighteenth century. This novel technology was further advanced in the years 1763–75 by the Scottish engineer James Watt, who adapted the engines for the operation of factory machinery, proliferating its commercial use".

[3] "In 1798, the English scholar Thomas Malthus offered a plausible theory for the mechanism that had caused living standards to remain stagnant, effectively trapping societies in poverty, since time immemorial. He argued that whenever societies managed to bring about a food surplus through technological innovation, the resulting boost in living standards could only ever be temporary as it would lead inevitably to a corresponding rise in birth rates and a reduction in mortality rates. It was just a matter of time, therefore, before the ensuing population growth would deplete the food surpluses, and thus living conditions would revert to subsistence levels, leaving societies as poor as they had been before the innovation. […] Ironically, however, just as Malthus completed his treatise and pronounced that this 'poverty trap' would endure indefinitely, the mechanism that he had identified suddenly subsided and the metamorphosis from stagnation to growth took place" (Galor, 2023, p. 15).

Graph 2.

Global GDP in the long run.



Source: Global GDP (2024).

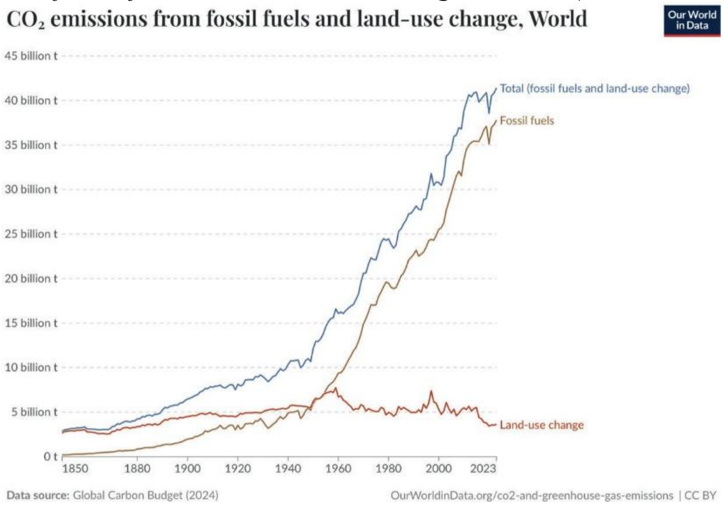
Graph 2 shows global GDP over the last 2023 years, adjusted for inflation and expressed in dollars, in 2021 prices. It can be seen that: (a) world wealth in the year 1 AD was US$ 247.70 billion; (b) in the year 1000 AD, US$ 284.85 billion; (c) in 1820, US$ 1.63 trillion; (d) in 1950, US$ 11.74 trillion; and (e) in 2023, US$ 166.65 trillion.

The last 70 years have seen more production than the entire previous history of the Homo Sapiens species. Between 2022 and 2023, the increase in world pro- duction was 5.27 trillion dollars—greater than the entire world production of the 19th century, for example. In absolute numbers, the increase in world wealth is a good thing. However, another figure, which can be related to the increase in world population and the increase in world production, is quite worrying: the global emission of carbon dioxide (CO_2) over the last 170 years.

With economic (and productive) growth, there has been a considerable increase in human interference in nature, which is illustrated by the greater emission of CO_2. Graph 3 illustrates the production of CO_2 by human hands through land use and the burning of fossil fuels.

Graph 3.

CO_2 emissions from fossil fuels and land-use change, World (between 1850 and 2023).



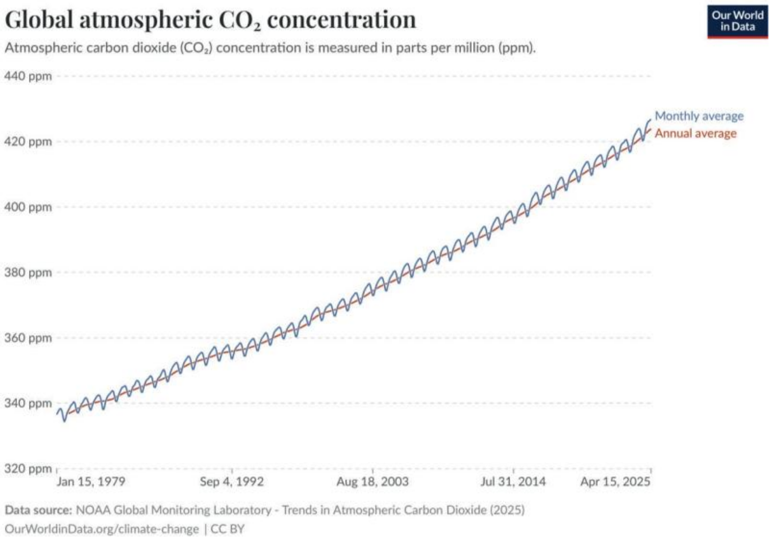
Source: Richier, Roser and Rosado (2020).

Graph 3 shows that: (a) the emission of CO2 by human hands in 1850 was 2.84 billion tons per year (2.64 billion tons from land use and 196.85 million tons from burning fossil fuels); (b) in 1955, there was a reversal, and for the first time in human history fossil fuel burning became the largest cause of CO2 emissions (7.44 billion tons from fossil fuel burning and 7.12 billion tons from land use; and (c) in 2023, 40.83 billion tons of CO2 were released (37.79 tons from fossil fuel burning and 3.62 billion tons from land use).

Graph 4 shows the atmospheric CO2 concentration from 1979 to 2023, given that the CO2 released into the atmosphere remains there.

Graph 4.

Global atmospheric CO_2 concentration: the concentration of carbon dioxide (CO_2) in the atmosphere is measured in parts per million (ppm) (from 1979 to 2025).



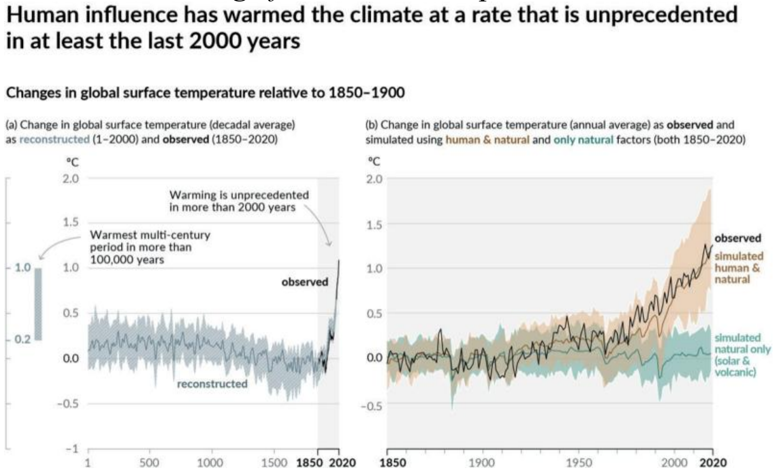
Sources: NOAA Global Monitoring Laboratory, 2025; Richier, Roser and Rosado (2020).

Looking at Graph 4, it can be seen that: (a) the atmospheric CO_2 concen- tration increased from 336.85 ppm (part per million) in 1979 to 367.79 ppm in 1999; (b) in 2015, of the 12 months, 8 reached the 400 ppm mark; (c) in 2016, the 400 ppm mark became permanent in all months. The annual average for 2016 was 404.21 ppm; and (d) in 2024, the annual average was 422.80 ppm.

It can be seen from the above graphs that there is a correlation between the Industrial Revolution and the resulting population increase and its consequences (increased production, increased CO2 emissions and concentration in the atmo- sphere). How does this relate to the rise in temperature?

Graph 5.

Human influence on the warming of the earth’s temperature over the last 2,000 years.



Source: IPCC (2021, p. 6).

Graph 5 shows the climate change from the year 1 AD to 2020. It can be seen that there has been a drastic change since the 20th century. The gray shad- ing between 1 AD and 2020 is a reconstruction based on paleoclimate research. The black line, from 1850 to 2020, comes from direct observations. Taking into account simulations of no human interference (green shading), the tendency was for temperatures to change in line with those that occurred in the years before the 20th century.

Currently, it can be said that the warming caused by humans in the glob- al-mean surface air temperature (GSAT) between 2010 and 2019, as compared to the 1850-1900 period, is around 0.8°C to 1.3°C, with the warming found to be 0.9°C to 1.2°C, which means that natural forces have only acted between −0.1°C and +0.1°C in temperature variation (Eyring et al., 2021).

Until the mid-1990s, it is likely that human-induced destruction of the ozone layer was largely responsible for global warming. However, in the last 30 years, the release of GHGs is the main culprit in climate change (Eyring et al., 2021).

GHGs are made up of the aforementioned carbon dioxide (CO2), methane (CH4), with 1,866 parts per billion (ppb) released in 2019, and nitrous oxide (N2O), with 332 ppb emitted in 2019. In 2019, CO2 concentrations in the atmosphere were the highest in the last 2 million years, and CH4 and N2O concentrations are the highest in the last 800,000 years. Furthermore, the increases in CO2 (47%) and CH4 (156%) concentrations, as compared to 1750, are much higher than the changes caused naturally over the last

800,000 years. GHG emissions modify the radiative properties of the atmosphere, which causes the atmosphere to warm (Lee; Romero, 2023).

The average increase in global temperature due to human influence has led to extreme weather events such as heat waves, heavy rainfall, droughts, and tropical cyclones (Lee; Romero, 2023).

a) Extreme heat has become more frequent since the 1950s, while extreme cold has become less frequent. There has also been an increase in marine heat waves since the 1980s.

b) The number and intensity of rainfall has increased since the 1950s in various parts of the world, such as South Asia, East Asia, and West Africa, while elsewhere there has been an increase in droughts.

c) In the last four decades, there has been an increase in category 3, 4, and 5 tropical cyclones, as well as a higher incidence in places that used to have less frequent cyclones.

d) Droughts, fires, and floods have also increased in various locations (Lee; Rome- ro, 2023).

As is evident, it is a fact that human beings have altered the climate in a way that has never occurred in human history. A question that must now be asked is: What economic impacts does climate change have?

3 ECONOMIC IMPACTS OF CLIMATE CHANGE

In recent decades, scientists have improved climate studies by using state- of-the-art computer climate models. In this sense, theoreticians are working on estimates of warming by the end of the 21st century, which include assumptions about how much CO2 humanity will put into the atmosphere over the next few decades. These estimates vary between 1°C and 4°C (IPCC, 2021).

Research into the economic impacts of global warming, which lead to climate change, is complex for two reasons: (a) climate change is global, but is caused by local damage, which is difficult to measure; and (b) GHGs, because they remain in the atmosphere for a long time, cause long-term effects (Auffhammer, 2018).

It is important to understand the economic effects of climate change for the practical use of political decisions and for researchers. Political decisions are often made on the basis of inconsistent and even false information regarding the effects of GHG emissions. Economic sciences play a fundamental role in this process of understanding by explaining the benefits and costs of new forms of action (Car- leton et al., 2022).

In order to ascertain the economic impacts of climate change, it is necessary to assume what the economy will look like after changes in the climate. Such changes can be extensive, i.e. present in several sectors; and they can be inten- sive, which are more frequent actions. A researcher will consider two fundamental (counterfactual) questions: (1) what will the future climate be like? and (2) what will the reaction to climate damage be like? (Auffhammer, 2018).

Given the difficulty of dealing with the question of the future climate, since the levels of GHG released into the atmosphere are uncertain in the long term, the researcher resorts to computer global circulation models (GCM), which will present different scenarios of GHG emissions and the changes caused by each of these scenarios. In the case of a response to climate damage, it will be necessary to assume how individuals will react to certain meteorological variations (Auffham- mer, 2018).

One of these assumptions involves the relationship between climate change and the mortality resulting from such changes. Carleton et al. (2022) estimated mortality and temperature at certain ages, using statistical data collected from 40 countries covering 38% of the world’s population. Using an economic model, the authors established the temperature-mortality relationship for all regions of the planet. The research shows that very low or very high temperatures increase the mortality rate, especially for people over 65. It also shows, based on the rela- tionship between future climate forecasts, income, and population, the projected future risk of mortality due to climate change.

To make the projections, Carleton et al. (2022) divided the Earth’s surface into 24,378 regions and, for each of them, projected damage from climate change. In addition, they used a set of 21 global climate projections produced by NASA Earth Exchange (NEX), which provide daily temperature and precipitation until the year 2100. The climate projections were based on two standardized emissions scenarios[4]: (a) Representative Concentration Pathways 4.5 (RCP4.5, an emissions stabilization scenario) and 8.5 (RCP8.5, a scenario with intensive growth in fossil fuel emissions).

[4] The RCP (Representative Concentration Pathways) scenario illustrates scenarios with fossil fuel concentration levels. For the levels, see IPCC (2014).

Another piece of data used was the Shared Socioeconomic Pathways (SSP)[5], which describe a set of plausible scenarios of socioeconomic development over the twenty-first century. SSP2, SSP3, and SSP4 were taken into account, which produce scenarios that fall between RCP4.5 and RCP8.5 (Carleton et al., 2022). For expected population growth, data from the International Institute for Applied Systems Analysis (IIASA) was used, in addition to national population projections, which are based on population distributions within countries, based on satellite images. Projections of national income per capita are similarly derived from the SSP, which uses both the IIASA projections and the OECD Env-Growth model projections (Carleton et al., 2022).

The study used the value of a statistical life (VSL) to project, in dollars, the equivalent per year of the value per life-year lost as a result of climate change, considering the expected years of life and income in each region. The basis was the value of 10.95 million (2019 US dollars), projected by the Environmental Protection Agency (EPA), adjusted to each national reality (Carleton et al., 2022). Firstly, sensitivity to temperature variation was sought, based on the mortality rate for ages over 64 years, with income and climate as the basis for the models applied to 2015. The survey took into account countries with mortality data and countries based on estimates, including those without mortality data. It looked at the number of deaths for each region on a day with a temperature of 35°C. Predicted mortality was higher in locations with colder climates and lower in-comes. The global average mortality rate was 10.1 deaths per 100,000 inhabitants (11.7 deaths per 100,000 inhabitants in countries without mortality data, and 7.8 deaths in countries with mortality data) (Carleton et al., 2022).

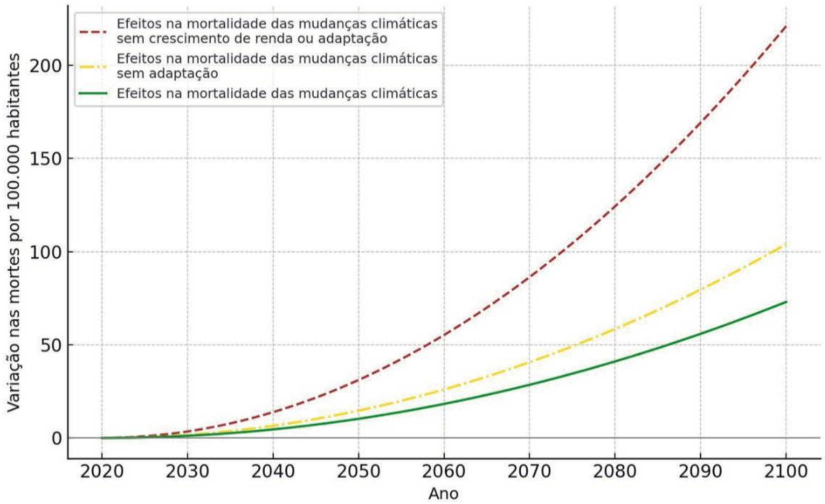
At another point, the mortality effects of climate change were sought in 2100, in the worst-case climate scenario (RCP8.5). The model considered income and population projections, inferred from economic (GDP per capita) and pop- ulation growth rates from 2000 to 2018. The estimates were based on a model based on the benefits of adaptation and the occurrence of income growth. The data showed that deaths caused by climate change will occur unevenly around the world, with higher mortality in warmer and poorer regions. Interestingly, in colder regions, the predicted mortality rate due to climate will decrease, as days with very low temperatures will be much less frequent. (Carleton et al., 2022).

[5] For the SSP scenarios, see IPCC (2021).

In a third situation, Carleton et al. (2022) illustrated the variation in deaths attributed to the effects of climate change (per 100,000 inhabitants) over time, considering different scenarios, represented in Graph 6, whose vertical axis mea- sures the change in deaths per 100,000 inhabitants, and the horizontal axis, the year (2020-2100).

Graph 6.

Time series of the projected effects of climate change on mortality[6].



Source: prepared by the authors based on information from Carleton et al. (2022).

The dashed red line represents a pessimistic scenario, with no economic growth or adaptation measures, resulting, among the possibilities presented, in the highest number of deaths due to climate change, culminating in 221 deaths per 100,000 inhabitants in 2100. The dotted yellow line considers economic growth, but without adaptation, resulting in 104 deaths per 100,000 inhabitants in 2100. The solid green line includes both economic growth and adaptation mea- sures, showing the smallest increase in mortality in 2100: 73 deaths per 100,000 inhabitants, which is still a significant number of deaths.

Even with economic growth and adaptation to climate change, without an effective reduction in CO² emissions in the coming decades, human-induced cli- mate change will have significant impacts on global mortality over the following eras.

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[6] Mortality effects of climate change without income growth or adaptation
Mortality effects of climate change without adaptation
Mortality effects of climate change Changes in deaths per 100.000 population Year

Carleton et al. (2022) indicate that the monetization of mortality due to climate change, in the worst case scenario (RCP8.5), would be equivalent of 3.2% of global GDP in 2100, falling to 0.6% of global GDP if GHG emissions were reduced in the coming years (RCP4.5). The researchers pointed out, as already seen in Auffhammer (2018), that it is difficult to project the exact impacts, given the factors that can vary throughout the 21st century, such as policy, technological advances, and demographics. However, when adjusting to other scenarios, while maintaining the level of emissions, a considerable economic loss was found in all the new possibilities.

When estimating the impacts for different regions, Carleton et al. (2022) found considerable variation between them. In the worst-case estimate (RCP8.5), China would have estimated losses of 1.9% of GDP, the United States 1.0%, India 6.0%, Pakistan 27.5%, Bangladesh 18.5%, Europe 0.1%, and sub-Saha- ran Africa 8.4%. As for mortality caused by climate change, China would have 1.4 deaths per 100,000 inhabitants; the United States, −0.2 deaths; India, 60.6 deaths; Pakistan, 322.4 deaths; Bangladesh, 213.8 deaths; Europe, −95.5 deaths; and sub-Saharan Africa, 121.3 deaths per 100,000 inhabitants.

Finally, Carleton et al. (2022) emphasized three difficulties that persist with- in the research presented on climate change: (a) migration – research is unable to predict possible migratory waves due to climate change, despite the evidence showing how countries struggle to deal with and accept large numbers of migrants;

(b) the role of humidity in historical mortality-temperature relationships – despite evidence that humidity influences human health, there is not much research that correlates humidity with climate change, and therefore its role in predictions of mortality due to climate change; and (c) the exact role of technological advances in relation to adaptive capacity in the face of climate change, which can reduce the costs of goods that are used to deal with climate change.

Even with the difficulties presented in obtaining an accurate prognosis of an- thropogenic climate change, there is a strong indication that climate change will bring economic, social, and existential damages to future generations.

4 CLIMATE CHANGE AND ITS LEGAL IMPLICATIONS IN THE BRAZILIAN SCENARIO

As Reis, Kokke and Couto (2022) rightly point out, Environmental Law is inter- and transdisciplinary par excellence, which justifies the first part of this article and the transition to reflections on the Brazilian legal scenario of climate change.

Climate change is unique in its impacts. First, because it implies the produc- tion of harmful effects that cannot be restricted territorially or temporally. Climate change in the Amazon biome does not only have an effect in the Amazon, but has repercussions throughout Brazil, South America, and the world. Furthermore, the effect is trans-temporal, in the sense that it affects not only present generations, but especially future generations. Climate damage implies an intergenerational environmental liability that jeopardizes the quality of life of present generations and also impacts their own economic subsistence in the future.

On the other hand, disregarding harmful environmental effects across generations is likely to provoke crisis situations and future confrontations on the levels of distributive justice. The crisis becomes acute in relation to the goods shared (or intended to be shared) by the cohabitants of the generations to come, a fact that encompasses crises between existing states or political communities, ranging from emigration and refugees for environmental reasons to war over the predominance of environmental goods necessary for life.

At this level of crisis, there is a predictable increase in imbalances between rich and poor countries, as Brown-Weiss (2008, p. 622) warns in relation to the effects of climate change, since “climate change will strengthen the economic di- visions which already exist between countries, since some countries will have a greater capacity to adapt than will others”.

Harmful climate effects impact fauna and flora, impact landscapes and water structures, impact food production and biodiversity. Variations in global tem- peratures are linked to environmental disasters, floods, devastating heat waves, droughts, and imbalances of all kinds. In this sense, Garbaccio, Bandeira and D’Isep (2018) situate the climate as a common heritage of humanity, a fact that attracts the assessment of responsibilities and reparation for damages that are pro- jected onto it. The risk and negative effects of climate change imply the opening of specific lawsuits, legal actions that deal directly or indirectly with damage to the climate, configured as a legal asset itself.

The Federal Supreme Court (STF), in several cases, most notably ADC 42, has already admitted—both from a normative point of view and from a factual and scientific point of view—the anthropogenic implication in destabilizing the climate, with actions and omissions that affect the ecosystem balance and cause climate dysfunction (Brasil, 2019). For its part, the Superior Court of Justice (STJ) has even recognized climate change as a topic already internalized by pos- itive law and, consequently, has understood the climate as a diffuse legal asset:

> 9. It is everyone's duty, whether they own property or not, to ensure the preservation of mangroves, which is increasingly necessary, especially in times of climate change and rising sea levels. Destroying them for direct economic use, under the permanent incentive of easy profit and short-term benefits, draining or landfilling them for real estate speculation or land exploitation, or turning them into a garbage dump are serious offenses against the ecologically balanced environment and the well-being of the community, behavior that must be promptly and energetically curbed and pun- ished by the Administration and the Judiciary[7] (Brasil, 2007, p. 3, free translation).

This applies to the express constitutional determination to protect the eco- logically balanced environment and preserve and restore essential ecological pro- cesses, provided for as a fundamental right in Art. 225 of the Constitution of the Federative Republic of Brazil (CRFB; Brasil, 1988). The contours of climate damage are diverse and unique, giving rise to a new claim for compensation for environmental damage, specifically related to the climate. Climate-related environmental damage is cumulative, in that it continually adds up in its production and scale of effects, and also appears to be synergistic, in that harmful conduct is not just a sum, but the production of a synthesis of effects that result in unpredictable consequences that are difficult to reverse, if not irreversible.

[7] In the original: "9. É dever de todos, proprietários ou não, zelar pela preservação dos manguezais, necessidade cada vez maior, sobretudo em época de mudanças climáticas e aumento do nível do mar. Destruí-los para uso econômico direto, sob o permanente incentivo do lucro fácil e de benefícios de curto prazo, drená-los ou aterrá-los para a especulação imobiliária ou exploração do solo, ou transformá- los em depósito de lixo caracterizam ofensa grave ao meio ambiente ecologicamente equilibrado e ao bem-estar da coletividade, comportamento que deve ser pronta e energicamente coibido e apenado pela Administração e pelo Judiciário".

In this sense and in this scenario, climate litigation presents itself as a claim of liability for specific environmental damage, marked by the peculiarity of seek- ing to have illegal emitters of GHGs condemned to internalize the negative ex- ternality they have produced to the detriment of society. Climate litigation aims to assign individualized responsibility for reparation due to the agent's illegitimate contribution to the broad and complex scenario of environmental damage that has arisen.

Climate litigation is advancing with unparalleled force on the global legal scene, given that environmental quality and the duty of intergenerational equity appear to be a right to be protected by states and society as a whole. International conventions and domestic laws have been put in place along these lines. Those who unreasonably or illegitimately engage in activities that result in an additional illegal source of GHG emissions should be held accountable for climate damage, bearing the burden individually and in the estimated proportion of their contri- bution to repairing the environmental imbalance to which they have contributed. Climate litigation is based on the foundation of environmental justice, which aims to assign a specific burden of reparation in the face of complex dam- age, considering the prominence of illicit actions that affect ecosystems based on the climate. Gabriel Wedy, in an article published at the Columbia Law School, highlights the scope of climate litigation in Brazil:

> In such context, it is possible to see that there is recent and still fragile climate litigation in Brazil. It is important to mention that the Act 12.187/2009, which instituted the National Policy on Climate Change, with imperfections and abstrac- tions, is a considerable progress as a milestone in fighting climate change and global warming.17 This act clearly incorporates the concept of international treaties and agreements on environmental protection, which is, in fact, extremely positive. The legislation is regulated by the Decree 7.390/2010, which provides, amongst oth- er important issues, the baseline of emissions of greenhouse gases for 2020 to be estimated in 3.236 GtCO2-eq. Thus, the corresponding absolute reduction was established between 1.168 Gt-CO2-eq and 1.259 GtCO2-eq, 36.1% and 38.9% emission decrease, respectively (Wedy, 2017, p. 23).

In this sense, the generation of GHGs that constitute illicit sources of emis- sions entails direct liability for those responsible for the emissions, measured on the basis of the emissions and their representation, according to the Social Cost of Carbon. Civil liability has its own connotation and conformation.

> There is no doubt that unlawful acts such as burning, deforestation or pollutant emissions, all of which generate greenhouse gas emissions, can be the subject of climate litigation brought by filing public civil actions or popular climate actions[8] (Kokke; Wedy, 2021, p. 53, free translation).

Climate litigation is defined by unlawful or harmful emissions of GHGs, and their reparatory value is given by estimating the social cost of carbon mea- sured by the amount that was emitted.

In addition, climate litigation has budgetary aspects, after all, the state will increasingly be required to provide resources to respond to environmental disas- ters and situations of exclusion to which individual polluters have contributed with a plus of illegitimate exploitation of natural resources. Climate litigation is a global issue.

> Nor are victories in climate litigation a chimera. The recent U.S. Supreme Court de- cision in Massachusetts v. EPA, which will force EPA to revisit whether to regulate carbon under the Clean Air Act, is the most well known climate victory. In so doing, the Supreme Court found that the risk of rising sea levels alleged by the plaintiffs was sufficiently "real" to afford Massachusetts standing to raise its climate change- based claim. Other courts in the US and Australia, for example, have extended standing to private parties pressing climate change claims. Significant substantive victories have also required, for example, the assessment of climate impacts in the permitting of greenhouse gas emitting activities, in decisions to provide financing, and in requirements to reduce gas flaring associated with oil refineries. These victo- ries are likely just the tip of the litigation iceberg, but win or lose, climate litigation strategies have harkened in a new era of climate politics (Hunter, 2008, p. 18-19).

Climate damage is linked to the emitting source and the proportion of dif- fusion in terms of GHGs, as well as the impairment of carbon fixation pathways in its stock cycle in the ecosystem. Rosa (2023) defines climate damage in terms of the current possibility of identifying the source, the causal link and liability for climate damage. Along these lines, "Direct climate damage is therefore the result of an individualizable sum of emissions and sink suppressions"[9] (Rosa, 2023, p. 378, free translation).

Climate litigation thus demands a new paradigm of perception, which takes into account the contribution of island acts as part of complex effects on the scale of the

[8] In the original: "Não existe dúvida que atos ilícitos como queimadas, desmatamentos ou emissões de poluentes, todos geradores de emissões de gases de efeito estufa, podem ser objeto de litígios climáticos instaurados com o ajuizamento de ações civis públicas ou ações populares climáticas".

[9] In the original: "O dano climático direto é, por conseguinte, o resultado de um somatório individualizável de emissões e de supressões de sumidouros".

balance of ecological functions and environmental quality. Specifically in relation to the present action, its purpose is to repair the climate damage caused by illegal interventions in environmentally protected areas.

Climate change, from a legal perspective, is a normative expression. It is a fixed issue that is not subject to justification, much less debate regarding its existence. Climate change is established normatively, and the evaluation of its application is based on Law 12.187/2009, which establishes the National Policy on Climate Change (PNMC; Brasil, 2009). It is thus an established legal primacy, immune to questioning, as this would be like questioning the very validity and effectiveness of a legitimately established norm.

Climate change is not a hypothesis, it is a starting point already recognized by Brazilian legislation, from which the discourse of application must address this starting point in order to assess the framework of the norm. Article 2, VIII, of Law 12.187/2009 defines climate change as "a change in climate that can be di- rectly or indirectly attributed to human activity that alters the composition of the global atmosphere and that is added to that caused by natural climate variability observed over comparable periods"[10] (Brasil, 2009, free translation). Associating and identifying the panorama of climate damage, it follows that those responsible for irregular sources of GHG emissions must be held accountable for the effects on biomass and climate imbalance that their anthropogenic activity has caused.

5 CONCLUSION

Initially, this article defined climate change and global warming. By analyz- ing graphs, it showed the correlation between the increase in world population, the increase in world wealth, the increase in global CO2 emissions into the atmo- sphere, the increase in the global concentration of CO2 in the atmosphere and the accelerated increase in the global average temperature, showing that the acceler- ation of global warming is due to human interference. The text is also based on scientific evidence that shows how this human interference has caused significant changes in the climate over the last 150 years.

[10] In the original: "mudança de clima que possa ser direta ou indiretamente atribuída à atividade humana que altere a composição da atmosfera mundial e que se some àquela provocada pela variabilidade climática natural observada ao longo de períodos comparáveis".

Having noted human interference in current climate change, the text sought to discuss the economic impacts of climate change caused by anthropogenic ac- tions, focusing on the example of the influence of climate change on the level of world mortality by the year 2100.

The study therefore showed evidence of human interference in climate change and, through examples, how society will suffer increasingly significant economic impacts throughout the 21st century. Based on the indications shown, public managers can be presented with efficient ways of alleviating the dramatic situation in which humanity finds itself. On the other hand, the repercussions and implications of climate change affect and determine specific litigation.

Climate litigation is based on the occurrence of climate damage, i.e. unlaw- ful or illegitimate GHG emissions that will contribute to climate change. In ad- dition, illicit actions that involve illegal or illegitimate suppression of carbon sinks also lead to liability for climate damage, since they prevent or harm the exercise of ecosystem resources for climate regulation.

The legal categorization of climate damage is a direct normative implication, attracting civil liability for reparations to agents who, regardless of fault, have acted causally in the emission of GHG through illegal practices. The valuation of liability, on an individual basis, can also be obtained, specifying all the factors determining the litigation and the reparatory implications. This is done by esti- mating the GHGs unlawfully or illegitimately emitted, valued according to the social cost of carbon and taking into account the affected carbon stock.

Climate litigation does not have a restriction or delimitation that makes it confusing with classic environmental litigation, relating to the reparation of the affected area. Climate damage goes beyond material environmental damage, im- plying effects on the ecosystem as a whole, derived from GHG emissions in their cumulative and synergistic content. The economic and socio-economic repercussions, as well as the implications for human existence itself, described and argued throughout this article, demonstrate the autonomy and implication of climate damage, which legally and technically support reparation claims for individual- ized attribution of responsibility.

REFERENCES

AUFFHAMMER, M. Quantifying economic damages from climate change. Journal of Economic Per- spectives, v. 32, n. 4, p. 33-52, 2018. Available from: https://pubs.aeaweb.org/doi/pdfplus/10.1257/

jep.32.4.33. Access on: Oct. 15, 2023.

BRASIL. [Constituição (1988)]. Constituição da República Federativa do Brasil. Brasília, DF: Presidência da República, 1988. Available from: https://www.planalto.gov.br/ccivil_03/constituicao/ constituicao.htm. Access on: Aug. 11, 2025.

BRASIL. Lei n. 12.187, de 29 de dezembro de 2009. Institui a Política Nacional sobre Mudança do Clima – PNMC e dá outras providências. Diário Oficial da União: seção 1, Brasília, DF, p. 109, 29 dez. 2009. Available from: https://www.planalto.gov.br/ccivil_03/_ato2007-2010/2009/lei/l12187. htm. Access on: Aug. 11, 2025.

BRASIL. Supremo Tribunal Federal. Ação Declaratória de Constitucionalidade n. 42. Rel. Min. Luiz Fux, Tribunal Pleno, julgado em 28 fev. 2018. Diário da Justiça Eletrônico, Brasília, DF, n. 175, publ. 13 ago. 2019. Available from https://pesquisadje-api.tjdft.jus.br/v1/diarios/pdf/2019/154.pd- f#page=0. Access on: Aug. 11, 2025.

BRASIL. Supremo Tribunal de Justiça. Recurso Especial 650.728/SC. Processual civil e ambiental. Natureza jurídica dos manguezais e marismas. Terrenos de marinha. Área de preservação permanente. Aterro ilegal de lixo. Dano ambiental. Responsabilidade civil objetiva. Obrigação propter rem. Nexo de causalidade. Ausência de prequestionamento. Papel do juiz na implementação da legislação ambi- ental. Ativismo judicial. Mudanças climáticas. Desafetação ou desclassificação jurídica tácita. Súmula 282/STF. Violação do art. 397 do CPC não configurada. Art. 14, § 1°, da Lei 6.938/1981. Recor- rente: H Carlos Schneider s/a Comércio e Indústria e outro. Recorrido: Ministério Público Federal. Relator Min. Herman Benjamin, 23 de outubro de 2007. Available from: https://www.stj.jus.br/ websecstj/cgi/revista/REJ.cgi/ATC?seq=3463400&tipo=0&nreg=&SeqCgrmaSessao=&CodOrgaoJg- dr=&dt=&formato=PDF&salvar=false). Access on: Aug. 11, 2025.

BROWN-WEISS, E. Climate change, intergenerational equity, and international law. Vermont Jour- nal of Environmental Law, Vermont, v. 9, p. 615-627, 2008. Available from: https://scholarship.law. georgetown.edu/cgi/viewcontent.cgi?params=/context/facpub/article/2637/&path_info=Climate_ change_Intergenerational_Equality_and_Intl_Law.pdf. Access on: Aug. 11, 2025.

CARLETON, T. et al. Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits. The Quarterly Journal of Economics, v. 137, n. 4, p. 2037-2105, nov. 2022. Available from: https://academic.oup.com/qje/article/137/4/2037/6571943. Access on: Oct. 15, 2023.

EYRING, V. et al. Human influence on the climate system. In: MASSON-DELMOTTE, V. et al. (ed.). Climate change 2021: the physical science basis. Contribution of

Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, 2021. p. 423-552. Disponível em: https://www.ipcc.ch/report/ar6/wg1/downloads/ report/IPCC_AR6_WGI_Chapter03.pdf. Access on: Oct. 25, 2023.

GALOR, O. A jornada da humanidade: as origens da riqueza e da desigualdade. Tradução Antenor Savold Jr. Rio de Janeiro: Intrínseca, 2023.

GARBACCIO, G.; BANDEIRA, G. N. C. S. M.; D'ISEP, C. F. M. Climat: un patrimoine commun de l'humanité. Revista Jurídica – UNICURITIBA, Curitiba, v. 1, n. 50, p. 147-184, 2018. Available from: http://revista.unicuritiba.edu.br/index.php/RevJur/article/view/2567/371371372. Access on: Oct. 11, 2024.

GLOBAL GDP over the long run. Our World In Data, 2024. Available from: https://ourworldinda- ta.org/grapher/global-gdp-over-the-long-run?time=earliest.2023#sources-and-processing. Access on: Aug. 9, 2025.

HISTORICAL GHC emissions. Climate Watch, 2021. Disponível em: https://www.climatewatchda- ta.org/ghg-emissions?chartType=area&end_year=2018&start_year=1990. Access on: Oct. 15, 2023.

HUNTER, D. B. The implications of climate change litigation for international environmental law-making. American University Washington College of Law, Washington College of Law Research Pa-

per, n. 2008-14, 2008. Available from: http://ssrn.com/abstract=1005345. Access on: Aug. 11, 2025.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. Summary for policymakers. In: EDENHOFER, O. R. et al. Climate change 2014: mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, 2014. Available from: https://www.ipcc.ch/site/ assets/uploads/2018/02/ipcc_wg3_ar5_summary-for-policymakers.pdf. Access on: Nov. 26, 2023.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. Summary for policymakers. In: MASSON-DELMOTTE, V. et al. (ed.). Climate change 2021: the physical science basis. Contribu- tion of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, 2021. p. 3-32. Available from: https://www.cam- bridge.org/core/services/aop-cambridge-core/content/view/8E7A4E3AE6C364220F3B76A189C- C4D4C/stamped-9781009157889pre2_3-32.pdf/summary-for-policymakers.pdf. Access on: Nov. 19, 2023.

KOKKE, M.; WEDY, G. Litigância climática no plano internacional: análises comparativas. Revista dos Tribunais, São Paulo, v. 110, n. 1023, p. 39-58, jan. 2021.

LEE, H.; ROMERO, J. (ed.). Climate change 2023: synthesis report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC, 2023. Available from:

https://www.ipcc.ch/report/ar6/syr/downloads/re-port/IPCC_AR6_SYR_LongerReport.pdf. Access on: Nov. 16, 2023.

MATHIEU, E.; RODÉS-GUIRAO, L. What are the sources for Our World in Data's population estimates? Our World In Data, 2022. Available from: https://ourworldindata.org/population-sources. Access on: Oct. 15, 2023.

NATIONAL ACADEMIES OF SCIENCES, ENGINEERING, AND MEDICINE. About us.

Available from: https://www.nationalacademies.org/about. Access on: Nov. 20, 2023.

NOAA GLOBAL MONITORING LABORATORY. Global atmospheric CO_2 concentration. Our World In Data, 2025. Available from: https://ourworldindata.org/grapher/global-co2-concentration. Access on: Aug. 9, 2025.

REIS, E. M. B.; KOKKE, M.; COUTO, M. J. Aplicação interdisciplinar e transdisciplinar nos es- paços administrativos decisórios em matéria ambiental. Veredas do Direito, Belo Horizonte, v. 19, n. 44, p. 153-181, maio/ago. 2022. Available from: http://www.domhelder.edu.br/revista/index.php/

veredas/article/view/2315. Access on: Mar. 10, 2025.

RICHIER, H.; ROSER, M.; ROSADO, P. CO_2 and greenhouse gas emissions. Our World In Data, 2020. Available from: https://ourworldindata.org/co2-and-greenhouse-gas-emissions. Access on: Aug. 9, 2023.

ROSA, R. S. M. Dano climático: conceito, pressupostos e responsabilização. São Paulo: Tirant lo Blanch, 2023.

ROSER, M. et al. Economic growth. Our World In Data, 2023. Available from: https://ourworldin- data.org/economic-growth. Access on: Aug. 9, 2023.

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE. Fact sheet:

climate change science – the status of climate change science today. Bonn: UNFCC, 2011. Available from: https://unfccc.int/files/press/backgrounders/application/pdf/press_factsh_science.pdf. Access on: Oct. 25, 2023.

WEDY, G. Climate legislation and litigation in Brazil. New York: Sabin Center for Climate Change Law, 2017. Available from: http://columbiaclimatelaw.com/files/2017/10/Wedy-2017-10-Cli- mate-Legislation-and-Litigation-in-Brazil.pdf. Access on: Aug. 11, 2025.

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Authors' participation

Both authors contributed equally to the preparation of this article.

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