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GREENHOUSE GASES AND CLIMATE CHANGE: FOUNDATIONS, EVIDENCE, AND CHALLENGES FOR THE LATIN AMERICAN AMAZON

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ABSTRACT

Objective: To analyze the physical foundations of the greenhouse effect, the main responsible gases, and the territorial implications of climate change in the Latin American Amazon basin.

Theoretical Framework: Based on scientific contributions from organizations such as the IPCC, FAO, NASA, and regional environmental observatories.

Method: A documentary review with a geographic-environmental focus, based on international and Latin American scientific sources, using a comparative approach.

Results and Discussion: A sustained increase in global temperature was identified, along with the retreat of the cryosphere, ocean acidification, and a higher frequency of extreme events. These phenomena directly affect ecosystems, territories, and human populations.
Research Implications: An integrated understanding of these impacts supports the development of mitigation policies, energy transition strategies, and forest conservation.

Originality/Value: This study connects global scientific evidence with local implications in Latin America, emphasizing the need for collective action to limit global warming to 1.5 °C and achieve climate justice.

Keywords: Global Warming, Amazon, Environmental Geography, Climate Change, Mitigation, Sustainabilit.

GASES DE EFECTO INVERNADERO Y CAMBIO CLIMÁTICO EN AMÉRICA LATINA: BASES FÍSICAS, EVIDENCIAS Y PERSPECTIVAS TERRITORIALES DESDE LA AMAZONÍA

RESUMEN

Objetivo: Analizar los fundamentos físicos del efecto invernadero, los principales gases responsables y las implicaciones territoriales del cambio climático en la cuenca amazónica latinoamericana.

Teórico Referencial: Se sustenta en aportes científicos de organismos como el IPCC, la FAO, la NASA y observatorios ambientales regionales.

Método: Revisión documental de carácter geográfico-ambiental, basada en fuentes científicas internacionales y latinoamericanas, con enfoque comparativo.

Resultados y Discusión: Se identificó un aumento sostenido de la temperatura global, acompañado del retroceso de la criosfera, acidificación oceánica y mayor frecuencia de eventos extremos. Estos fenómenos afectan directamente los ecosistemas, territorios y poblaciones humanas.

Implicaciones de la Investigación: La comprensión integrada de estos impactos permite fundamentar políticas de mitigación, transición energética y conservación forestal.

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Originalidad/Valor: Este estudio articula evidencias científicas globales con implicaciones locales en América Latina, destacando la necesidad de una acción colectiva para limitar el calentamiento global a 1,5 °C y alcanzar la justicia climática..

Palabras clave: Calentamiento Global, Amazonía, Sostenibilidad, Mitigación, IPCC, Energía Limpia.

GASES DE EFEITO ESTUFA E MUDANÇAS CLIMÁTICAS NA AMÉRICA LATINA: FUNDAMENTOS FÍSICOS, EVIDÊNCIAS E PERSPECTIVAS TERRITORIAIS DESDE A AMAZÔNIA

RESUMO

Objetivo: Analisar os fundamentos físicos do efeito estufa, os principais gases responsáveis e as implicações territoriais das mudanças climáticas na bacia amazônica latino-americana.

Referencial Teórico: Baseia-se em contribuições científicas de organizações como o IPCC, FAO, NASA e observatórios ambientais regionais.

Método: Revisão documental com enfoque geográfico-ambiental, fundamentada em fontes científicas internacionais e latino-americanas, utilizando uma abordagem comparativa.

Resultados e Discussão: Identificou-se um aumento contínuo da temperatura global, acompanhado do recuo da criosfera, acidificação dos oceanos e maior frequência de eventos extremos. Esses fenômenos afetam diretamente os ecossistemas, os territórios e as populações humanas.

Implicações da Pesquisa: A compreensão integrada desses impactos subsidia a formulação de políticas de mitigação, estratégias de transição energética e conservação florestal.

Originalidade/Valor: Este estudo articula evidências científicas globais com implicações locais na América Latina, destacando a necessidade de ação coletiva para limitar o aquecimento global a 1,5 °C e alcançar a justiça climática.

Palavras-chave: Aquecimento Global, Amazônia, Sustentabilidade, Mitigação, IPCC, Energia Limpa.

1 INTRODUCTION

The Earth's climate is a dynamic system resulting from the interaction between physical, chemical, and biological processes operating at different scales (Fresco & Kroonenberg, 1992; Hamidi, 2022). Its stability depends on the balance between the solar energy received by the Earth and the thermal energy it radiates into space, a condition that allows for the existence of liquid water and complex life (IPCC, 2021a).

Since the 19th century, this balance has been altered by human activity. The burning of fossil fuels, deforestation, and agro-industrial expansion have significantly increased the concentration of greenhouse gases (GHGs), intensifying global warming (Soeder, 2020; IPCC, 2021b; NASA, 2023). Although present in low concentrations, gases such as CO_2, CH_4, N_2O, and fluorinated gases have a high impact on the energy balance (Filonchyk et al., 2024). According to the IPCC, in 2023 CO_2 reached 419 ppm, the highest level in two million years (IPCC, 2021a; NOAA, 2024), causing a radiative imbalance that favors sustained global warming.

The consequences of this phenomenon are clear: glacier retreat, sea level rise, variations in precipitation, and increased intensity of extreme events (Hansen et al., 2016; IPCC, 2021b). These impacts affect ecosystems as well as territories and human societies.

In this context, the Amazon basin—which spans nine Latin American countries—plays a crucial role as a carbon sink and climate regulator. Its vegetation and soils store enormous amounts of carbon that, if released rapidly through deforestation or fires, could push the climate system past a point of no return. The transformation of these territories into net carbon emitters poses a direct threat to global stability (IPCC, 2021a).

From a geographical perspective, climate change is not only a physical process, but also a socio-spatial one. The Amazon, due to its biodiversity and dependence on its resources, offers a strategic space for analyzing the relationships between nature, territory, and power. The causes of its degradation respond both to global dynamics and to historical structures of inequality (Leff, 2004).

Authors such as Milton Santos (1996) and Porto-Gonçalves (2001) emphasize that territory is not only a physical base, but also a social construct shaped by development models and power relations. From this critical perspective, climate change is understood as a territorialized manifestation of the unequal expansion of capitalism over nature. This view allows us to analyze how climate change is reconfiguring land use, territorial occupation, and living conditions in the Amazon.

This article aims to analyze, from a geographical and environmental perspective, the physical and social processes that intensify the greenhouse effect, as well as the implications of climate change in Latin American Amazonian territories. It is based on a documentary review of sources such as reports from the IPCC, NASA, FAO, and regional observatories . The approach integrates global and regional scales to provide an interdisciplinary reading of climate change as a physical, territorial, and social phenomenon.

2 THEORETICAL REFERENCE

2.1 WHAT IS THE GREENHOUSE EFFECT?

The greenhouse effect is a natural process that is essential for keeping the Earth habitable. Without it, the global average temperature would be approximately –18 °C; thanks to its existence, it remains close to 15 °C, allowing for the presence of liquid water, climatic stability, and life as we know it (IPCC, 2021a; NASA, 2023). This phenomenon occurs because shortwave solar radiation passes through the atmosphere and heats the Earth's surface, which re-emits part of that energy in the form of infrared radiation. Greenhouse gases (GHGs)—such as water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3)—absorb and re-emit this radiation, preventing all the heat from escaping into space (NOAA, 2024).

This natural radiative equilibrium keeps the planet's temperature stable. However, the intensification of the greenhouse effect caused by human activities has altered the global energy balance. Since the Industrial Revolution, the burning of fossil fuels, deforestation, agricultural expansion, and industrial processes have increased the concentration of GHGs in the atmosphere, creating a positive energy imbalance in which the Earth retains more energy than it emits. This phenomenon has resulted in the global warming observed in recent decades (IPCC, 2021b).

2.2 MAIN GREENHOUSE GASES

GHGs are atmospheric components capable of absorbing and emitting infrared radiation, contributing to the maintenance of the Earth's thermal balance. However, when their concentrations rise above natural levels, positive radiative forcing occurs, intensifying global warming. Four of these gases are responsible for most of contemporary climate change: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases. The role of water vapor is coupled with that of other GHGs because as the climate becomes warmer, more water evaporates and water vapor in the atmosphere increases.

CO_2 comes mainly from the combustion of fossil fuels, land use change, and cement production. Its half-life in the atmosphere is centuries, making it the main contributor to global warming (IPCC, 2021b; NOAA, 2024).

CH_4 originates from enteric fermentation in livestock, rice paddies, landfills, and natural gas and oil leaks. It has a global warming potential 28 to 30 times greater than that of CO_2 over a 100-year period, although its atmospheric lifetime is shorter, approximately one decade (IPCC, 2021a).

Based on 20 years, which is the relevant period for efforts to avoid passing a climate tipping point, the impact of one ton of CH_4 is 80.8 times greater than one ton of CO_2 (IPCC, 2021a).

N_2O is mainly released through the use of nitrogen fertilizers and manure management. Its global warming potential is 273 times greater than that of CO_2, and its half-life exceeds a century (IPCC, 2021a; NASA, 2023).

Finally, fluorinated gases—of industrial origin—used in refrigeration and electronics have warming potentials exceeding 10,000 times that of CO_2 and can remain in the atmosphere for thousands of years (IPCC, 2021b).

2.3 TERRITORIAL AND SOCIO-ENVIRONMENTAL DIMENSIONS OF CLIMATE CHANGE

Beyond its physical mechanisms, climate change must be understood as a territorial and socio-spatial process, resulting from the unequal interaction between society and nature. From the perspective of critical Latin American geography, territory is conceived not only as a physical space, but also as a social construct marked by power relations, modes of production, and historical dynamics (Santos, 1996; Porto-Gonçalves, 2001).

In the Amazon region, this reality manifests itself in massive deforestation, land concentration, and the climate vulnerability of rural and indigenous communities. Environmental degradation processes are closely linked to historical structures of exclusion and the lack of land use planning, reproducing patterns of inequality that limit the population's adaptive capacity in the face of climate change (Costa et al., 2024; Hecht et al., 2024).

Thus, the analysis of greenhouse gases cannot be separated from its spatial dimension. Understanding climate change from the perspective of Latin American environmental geography implies recognizing that the Amazonian territories are simultaneously scenes of ecological crisis and strategic spaces for the construction of alternatives for sustainability and climate justice.

3 METHODOLOGY

This research was developed through a documentary and comparative review aimed at analyzing the physical, environmental, and territorial foundations of climate change, with an emphasis on the role of greenhouse gases (GHG) and their impact on the Latin American Amazon region. The study takes a qualitative-descriptive approach, characteristic of geographical and environmental reviews, whose purpose is to integrate scattered scientific knowledge and generate an interdisciplinary interpretation of the processes analyzed.

3.1 COLLECTION AND SELECTION OF SOURCES

Scientific documents, technical reports, and institutional databases published between 2018 and 2024 were collected and reviewed, prioritizing those that were peer-reviewed and internationally recognized. The main sources included reports from the Intergovernmental Panel on Climate Change (IPCC)—in particular the Sixth Assessment Report (AR6) and the Special Report on Global Warming of 1.5 °C (SR15)—, informational and technical resources from NASA and NOAA, FAO reports, and regional databases from the Greenhouse Gas Emissions Estimation System (SEEG). In addition, academic articles in indexed databases (Scopus, Scielo, Redalyc) and Latin American literature on environmental geography and climate justice were consulted.

3.2 COMPARATIVE ANALYSIS AND INTERDISCIPLINARY INTEGRATION

The analytical procedure was carried out in three phases: compilation and selection; comparative analysis; and interpretive synthesis. This methodological approach made it possible to contextualize global scientific information within a Latin American geographical framework, analyzing how changes in the climate system are expressed differently in the Amazonian territories.

The comparative review strategy also facilitated the identification of knowledge gaps and interdependencies between physical processes and socio-spatial dynamics. In summary, the methodology adopted provides a comprehensive view of climate change, not only as an atmospheric phenomenon, but also as an ecological, territorial, and political process linked to the unequal management of space and the contemporary environmental crisis.

4 ANALYSIS AND THEMATIC DISCUSSION

4.1 EVIDENCE AND CAUSES OF GLOBAL WARMING: WHY ARE THESE GASES INCREASING?

The increase in greenhouse gases (GHGs) in the atmosphere is not a random phenomenon, but a direct consequence of the development model adopted by human societies over the last two centuries (Jogdand, 2020). Since the Industrial Revolution, the burning of fossil fuels—coal, oil, and natural gas—deforestation, agricultural expansion, intensive livestock farming, and industrial processes have profoundly altered the natural balance of the climate system (IPCC, 2021a).

4.1.1 Sources of energy

The main source of CO_2 emissions comes from the use of fossil fuel-based energy. The burning of fossil fuels continues to be the main source of carbon dioxide (CO_2) emissions worldwide. Thermoelectric plants, land, air, and sea transport, as well as industrial processes, release large volumes of CO_2 when transforming coal, oil, and natural gas into useful energy. This energy pattern, inherited from the 19th-century industrial model, accounts for approximately 73% of global greenhouse gas (GHG) emissions, consolidating the energy sector as the main contributor to global warming (IPCC, 2021a; NASA, 2023).

Although significant progress has been made in recent decades in the development of renewable sources—such as solar, wind, and hydroelectric power—the transition to a low-carbon energy matrix is progressing slowly. Structural dependence on oil and coal, especially in emerging economies, limits compliance with the decarbonization commitments made in the Paris Agreement (2015). This persistent dependence reflects not only a technological challenge, but also a political and economic dilemma linked to development models and unequal access to clean energy at the global level.

4.1.2 Agricultural and livestock sources

The agricultural sector contributes significantly to emissions of methane (CH_4) and nitrous oxide (N_2O). Nitrous oxide is released when nitrogen fertilizers are applied to crops or during the management of manure and animal waste (IPCC, 2019; FAO, 2022).

Methane is mainly generated during enteric fermentation in ruminant livestock (cows, sheep, and buffalo) and in flooded rice paddies, where organic matter decomposes under anaerobic conditions. In Latin America, these types of emissions are particularly relevant, as the region is home to nearly 30% of the world's cattle, concentrated mainly in Brazil, Bolivia, Colombia, and Peru, countries that share the Amazon basin (FAO, 2022). The intensification of agriculture for export—soybeans, oil palm, sugarcane, and livestock—has contributed to accelerated tropical forest loss, increasing emissions and reducing the capacity of ecosystems to absorb carbon.

4.1.3 Deforestation and land use change

Deforestation is one of the most critical causes of the increase in greenhouse gases, especially in the Latin American Amazon region, where millions of hectares of forest are cleared each year to make way for livestock and extensive agriculture (IPCC, 2019). Forests act as natural carbon sinks, absorbing CO_2 through photosynthesis as long as they are growing. However, when they are destroyed, the carbon stored in the trunks, roots, and soils is released into the atmosphere, transforming these ecosystems into net sources of emissions.

Amazonian deforestation is not only driven by economic dynamics, but also by historical structures of inequality and land concentration. Fragmented environmental policies and the absence of effective land use planning exacerbate socio-spatial asymmetries, reproducing a cycle of ecological degradation and social exclusion. Estimates indicate that emissions from deforestation and forest degradation account for about 45% of total GHG emissions from Amazonian countries (SEEG, 2023). This process not only contributes to global warming, but also alters regional hydrological cycles, reducing evapotranspiration and the supply of water vapor that is transported by winds to regions outside the Amazon, thus reducing rainfall in much of South America (IPCC, 2021b).

4.1.4 Industrial processes and waste

Industrial processes—such as the production of cement, steel, fertilizers, and chemicals—release large amounts of CO_2 and N_2O. In addition, inadequate management of solid waste and wastewater generates methane emissions due to the anaerobic decomposition of organic matter in landfills and treatment plants.

These emissions tend to be concentrated in growing urban areas, where increased consumption, transportation, and industrialization increase the carbon footprint of cities (NASA, 2023).

4.1.5 Natural factors and climate feedbacks

Although human activities are primarily responsible for the increase in GHGs, there are also natural processes that influence atmospheric concentrations. Volcanic activity, solar variations, and climate system feedbacks (such as the release of methane from frozen soils or wetlands) can amplify the warming already initiated by human action (IPCC, 2021a).

For example, as global temperatures rise, thawing permafrost releases methane trapped for thousands of years, creating a vicious cycle that further accelerates warming.

The increase in greenhouse gases is therefore the result of a combination of intensive human activities and natural feedback processes. In the Amazon region, deforestation, agricultural expansion, and fossil fuel use are the main sources of emissions, compromising one of the most important ecological systems for regulating the planet's climate.

Understanding these causes is key to designing mitigation strategies that integrate the conservation of Amazonian ecosystems with sustainable, low-carbon economic development.

4.2 EVIDENCE OF GLOBAL WARMING

Global warming is the sustained increase in the average temperature of the Earth's climate system, caused mainly by the accumulation of greenhouse gases in the atmosphere. Scientific observations over the last few decades confirm that this phenomenon is unequivocal and that human influence is its main cause (IPCC, 2021a). The evidence comes from multiple sources—satellites, weather stations, ocean buoys and , ice records, and biological observations—which all point to profound and accelerating changes in the atmosphere, oceans, cryosphere, and terrestrial ecosystems (NASA, 2023; NOAA, 2024).

4.2.1 Global temperature rise

During the period 2011–2020, the average land surface temperature was 1.09 °C higher than in the pre-industrial period (1850–1900). This increase is the fastest observed in the last 2,000 years, and each of the last four decades has been successively warmer than the previous one (IPCC, 2021a).

Warming is not distributed evenly: continental areas are warming more than the oceans, and polar regions are experiencing temperature increases up to three times greater than the global average (NASA, 2023). Warming is less pronounced over the oceans, which cover 70% of the planet, and greater over continental areas such as the Amazon. This phenomenon, known as polar amplification, accelerates ice melt and alters the atmospheric currents that regulate the climate across the planet.

4.2.2 Changes in the oceans

The oceans act as a giant thermal regulator, absorbing approximately 91% of the excess heat generated by the intensified greenhouse effect. However, this "climate buffer" function has serious consequences:

- Ocean water expands thermally, contributing to sea level rise, which increased by an average of 3.7 mm per year between 2006 and 2018 (IPCC, 2021b).
- The oceans have absorbed between 20% and 30% of the CO_2 emitted by human activities since the 1980s, leading to widespread acidification.
- This acidification alters marine chemistry, affecting organisms such as corals, mollusks, and plankton, which form the basis of ocean food chains (NASA, 2023).

These combined processes are changing marine and coastal ecosystems, reducing their biological productivity and increasing the vulnerability of the human communities that depend on them.

4.2.3 Ice retreat and mass loss in the cryosphere

The cryosphere, which includes glaciers, ice sheets, snow, and permafrost, is undergoing unprecedented retreat. According to the IPCC (2021b), mass loss in Greenland and Antarctica has accelerated since the 1990s, becoming the main cause of sea level rise. Arctic sea ice has decreased in extent and thickness, reaching historic lows. In 2020, its summer area was the second lowest recorded since satellite observations began (NOAA, 2024).

In addition, the thawing of permafrost releases methane and carbon dioxide trapped for thousands of years, creating a positive feedback mechanism that further intensifies global warming.

4.2.4 Increase in extreme weather events

One of the most compelling pieces of evidence for climate change is the increase in the frequency and intensity of extreme weather events. According to the IPCC (2021a):

- Heat waves are now more frequent and prolonged in most terrestrial regions.
- Intense precipitation has increased, leading to more severe flooding.
- Agricultural and ecological droughts are more common due to the intensification of El Niño and Atlantic Dipole events.
- Intense tropical cyclones (categories 3–5) have been increasing in proportion over the last four decades.

In the Amazon basin, these trends are reflected in significant regional climate changes. Long-term studies show that the average temperature increased between 0.6 °C and 0.7 °C between 1949 and 2018, accompanied by a reduction in annual precipitation and a higher frequency of extreme droughts (Marengo & Souza Jr., 2018). Events such as the Atlantic dipole droughts in 2005 and 2010, the El Niño event in 2015–2016, and the simultaneous Atlantic dipole and El Niño events in 2023 and 2024 caused the loss of millions of hectares of forest and an increase in fires, temporarily transforming the Amazon from a carbon sink to a net carbon source (e.g., IPCC, 2021b).

4.2.5 Changes in ecosystems and biodiversity

Rising temperatures and changes in rainfall patterns are affecting terrestrial and aquatic ecosystems across the planet. In the Amazon region, there is increasing tree mortality, a reduction in carbon absorption capacity, and the migration of species to higher or wetter areas (IPCC, 2021b).

These processes alter the ecological functioning of the rainforest, reduce the resilience of ecosystems, and threaten the biodiversity and environmental services that sustain millions of people in South America.

The accumulated scientific evidence is overwhelming: the Earth's climate system is in positive energy imbalance, with visible and measurable consequences in all its components.

The atmosphere is warming, the oceans are accumulating heat, ice is melting, and extreme events are intensifying. For the Latin American countries that share the Amazon basin, these changes pose environmental, social, and economic risks that threaten the region's water, food, and ecological security. Observing and understanding this evidence is the first step in designing effective climate mitigation and adaptation strategies.

5 THE FUTURE OF THE CLIMATE

The Earth's climate future is not predetermined: it will depend on the human decisions made in the coming decades. Climate science has shown that the magnitude of global warming is directly related to the amount of greenhouse gases (GHGs) that remain in the atmosphere. In other words, every ton of carbon dioxide emitted today will influence tomorrow's climate (IPCC, 2021a).

The Intergovernmental Panel on Climate Change (IPCC) uses simulation scenarios called Shared Socioeconomic Pathways (SSPs), which describe different possible futures based on emission trajectories, economic development, and environmental policies. These scenarios make it possible to estimate how the planet's temperature will vary and what consequences will result from each model of society (IPCC, 2021b).

5.1 IPCC CLIMATE SCENARIOS

The IPCC's Sixth Assessment Report (AR6) proposes five main trajectories or scenarios:

- SSP1-1.9 (Global Sustainability): describes a world committed to sustainable development, international cooperation, and the use of clean energy. It is the only scenario compatible with the Paris Agreement's goal of limiting warming to 1.5°C above the pre-industrial global average.
- SSP1-2.6 (Moderate green development): follows a similar trend, but with a slower transition to decarbonization, reaching an increase of around 2 °C by 2100.
- SSP2-4.5 (Intermediate trend): represents the continuation of current policies, without profound transformations, with an estimated increase of 2.7°C.
- SSP3-7.0 (Fragmented World): characterizes a divided society, with regional conflicts, inequalities, and dependence on coal and oil, which would lead to warming of around 3.6°C.

- SSP5-8.5 (High emissions): assumes economic growth based on fossil fuels, with a global average temperature that could exceed 4.4 °C by the end of the century (IPCC, 2021b; NASA, 2023).

Each scenario is not a prediction, but a projection of what would happen depending on the social, political, and economic decisions made on a global scale. All of these scenarios assume that the climate will not pass a point of no return and escape human control.

5.2 THE CARBON BUDGET AND THE 1.5°C TARGET

The carbon budget represents the maximum amount of CO_2 that can still be emitted to limit global warming. According to the IPCC (2018), to have a 67% chance of not exceeding 1.5°C, only about 400 gigatons of additional CO_2 can be emitted from 2020 onwards. To achieve this, emissions must be reduced by 45% by 2030 and carbon neutrality must be achieved by 2050 (IPCC, 2018, 2021a). Exceeding this threshold carries a high risk of triggering irreversible processes, such as glacier collapse, desertification, and massive biodiversity loss.

The 1.5°C threshold could be exceeded before 2025, with serious consequences: major droughts in Brazil are expected to triple in frequency, which would make any tropical rainforest unsustainab ly (Price et al., 2022). This level is considered a global tipping point (Hansen et al., 2025), critical for the survival of the Amazon biome (McKay et al., 2022; Trisos et al., 2020). In addition, the Amazon is approaching other tipping points linked to the percentage of deforestation (Lovejoy & Nobre, 2018; Nobre et al., 2016), the lengthening of the dry season (Sampaio et al., 2019), and the recurrence of forest fires (Brando et al., 2025). According to Flores et al. (2024), between 10% and 47% of the Amazon could collapse before 2050.

Crossing these thresholds does not imply immediate collapse, but it does imply an increasing probability of collapse over time. If the Amazon rainforest collapses, the resulting emissions could trigger an "uncontrolled greenhouse effect," pushing the planet toward a "Greenhouse Earth" (Fearnside & Silva, 2023; Steffen et al., 2018).

In 2023, direct human emissions totaled 16 gigatons of carbon (UNFCCC, 2023). Without drastic reductions, indirect factors will further exacerbate warming: fires in drier climates, emissions from soil, permafrost thawing, and reduced ocean absorption of CO_2. In the Amazon, this would mean the collapse of ecosystem services, affecting agriculture and water supply (Martinez & Dominguez, 2014; Zemp et al., 2014), and increasing climate migration from regions such as northeastern Brazil. Finally, uncontrolled warming would lead to extreme temperatures of over

50°C, causing mass mortality in the region, even among urban populations, due to the collapse of essential services (Matthews et al., 2025; Raymond et al., 2020; Sherwood & Ramsay, 2023).

5.3 REGIONAL CONSEQUENCES FOR THE AMAZON BASIN

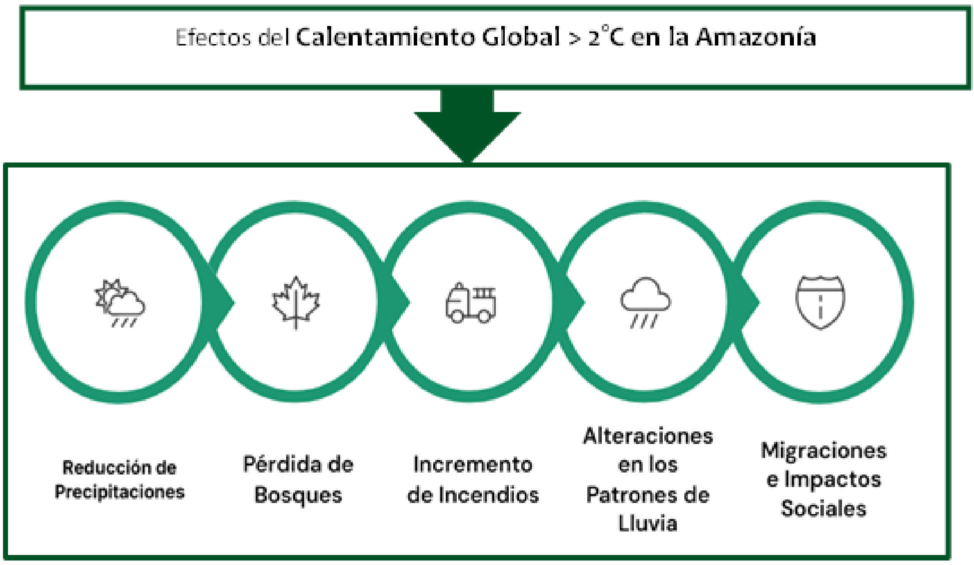
The IPCC climate scenarios warn that Latin American countries that share the Amazon basin will be particularly vulnerable to climate change. According to Guillermo Castro Herrera (2012), the climate crisis is reshaping the relationships between nature, economy, and territory in Latin America, demanding a new political geography based on sustainability. In the Amazon, these transformations are expressed in human displacement, loss of community territories, and conflicts over natural resources, which demand integrated approaches that articulate environmental justice and territorial planning.

If global warming exceeds 2°C above pre-industrial levels, the impacts on the Amazon basin would be much more severe than in a 1.5°C scenario. IPCC projections (2021c) foresee a notable reduction in rainfall and an increase in the frequency of prolonged droughts, compromising river recharge and water availability in large regions of South America.

This water stress could accelerate the transition of tropical forests to drier ecosystems, such as savannas, by exceeding ecological tipping points. In addition, an increase in forest fires is anticipated, releasing large amounts of carbon and exacerbating climate change. These transformations will alter the rainfall patterns that feed agricultural areas in the Southern Cone and the Andes, putting food security and rural livelihoods at risk. Finally, increased climate pressure will intensify human displacement and socio-environmental conflicts, particularly affecting rural and indigenous communities dependent on Amazonian ecosystems (IPCC, 2021c; FAO, 2022).

Figure 2

Projected effects of global warming above 2°C in the Amazon region.



Source: Adapted from IPCC, 2021c; FAO, 2022: The figure describes the projected effects of global warming above 2 °C in the Amazon region: The figure summarizes the main impacts associated with the increase in global average temperature, including reduced rainfall, forest loss, increased fires, changes in rainfall patterns, and migration with social effects resulting from climate change.

5.4 OPPORTUNITIES FOR CLIMATE ACTION

Despite the critical scenarios, science also offers a path of hope. The transition to a low-carbon development model can stabilize the climate if comprehensive measures are taken to address both the causes and effects of global warming (IPCC, 2019; FAO, 2022). Priority actions include the phasing out of fossil fuels and their replacement with clean renewable energies such as solar, wind, and sustainable biomass.

The protection and restoration of Amazonian forests is equally strategic: not only do they function as carbon sinks, but they are also fundamental to regional and global climate regulation. Added to this is the need to transform the agricultural sector, promoting sustainable practices such as agroforestry and silvopasture, which can reduce emissions and conserve soils. These strategies must be coordinated with greater international cooperation, especially in the cross-border management of the Amazon—a territory shared by nine countries—which requires coordinated conservation and climate governance policies (Leff, 2004; Porto-Gonçalves, 2001).

Environmental education and citizen participation are also essential to promote resilience, climate justice, and shared responsibility. However, these actions will only be effective if we avoid exceeding tipping points that, if surpassed, would lead to the mass death of human populations in the Amazon, rendering other social objectives irrelevant (IPCC, 2021;

Fearnside & Silva, 2023). Limiting warming to 1.5°C, as established in the Paris Agreement, is an ethical and civilizational imperative (IPCC, 2018). The climate fate of the planet will depend, to a large extent, on the decisions made by Latin American Amazonian countries regarding their forests and communities (Marengo & Souza Jr., 2018). As Santos (1996) warns, building sustainable territories requires transforming the historical power relations that subordinate nature to the market. The time to act is now (Castro Herrera, 2012; IPCC, 2021).

6 CONCLUSION

Climate change is one of the greatest challenges we face today. Scientific evidence shows that the planet is warming rapidly due to human activities, especially the increase in greenhouse gases such as CO_2, CH_4, and N_2O. This imbalance is altering the global climate, causing extreme phenomena that affect health, agriculture, and economic stability, especially in highly vulnerable tropical regions. The Amazon basin, an essential climate regulator and large carbon sink, faces growing threats from deforestation and agricultural expansion. If this trend continues, it could become a net source of emissions, accelerating global climate change.

The IPCC and other scientific sources agree: it is urgent to phase out fossil fuels, protect forests, and transform agriculture. This requires international cooperation, effective public policies, and recognition of the key role of local and indigenous communities. Limiting warming to 1.5°C is still possible, but it requires firm political decisions and immediate action. The climate future of the planet is at stake, and what is done today in the Amazon will be decisive for our common future.

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