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Understanding Global Climatic Shifts- A Comprehensive Review

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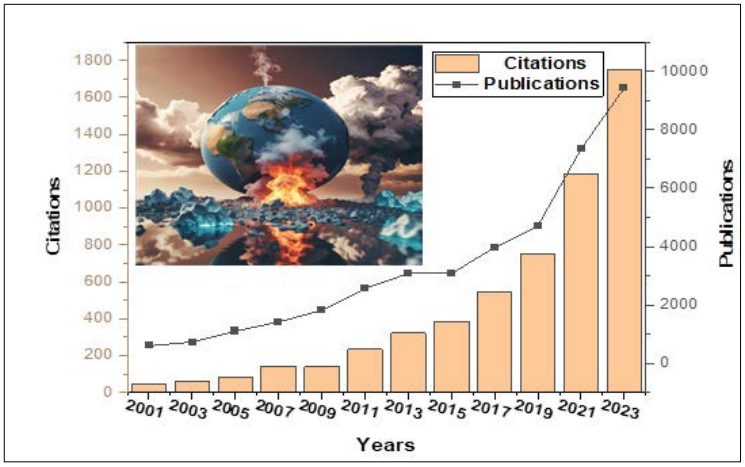
ABSTRACT

Climate change, spanning from tropical regions to polar zones, represents a significant and persistent alteration in weather patterns, posing a grave threat to all sectors of the global economy. This review seeks to shed light on the variability that is comprehensively eroding the sustainability of various sectors. The uniqueness of this review lies in its thorough synthesis of the most recent research and insights into global climatic changes, offering a holistic perspective that covers the causes, manifestations, impacts, and potential remedies to tackle this intricate issue. While numerous studies have delved into different facets of climate change independently, this review integrates diverse viewpoints from climate science, ecology, economics, and social sciences to provide a nuanced comprehension of the multifaceted challenges of climatic shifts. Furthermore, a discussion on the intricate relationship between climate change and other global crises, such as food security, water scarcity, and social inequality, underscores the interconnected nature of these challenges and the significance of integrated solutions. Additionally, the review has furnished valuable insights into potential adaptation and mitigation strategies to confront the challenges of climate change. Recent events like the coronavirus outbreak indicate that climate change exacerbates the issue of antimicrobial resistance, posing a new threat to human health through the proliferation of resistant microorganisms.

Moreover, the global tourism faces significant setbacks when climate change renders previously popular destinations less attractive. This review offers a detailed assessment of climate change mitigation and adaptation measures tailored to specific sectors mentioned above while considering the associated economic implications. Prioritizing efforts to mitigate the impacts of climate change is imperative, necessitating a global endeavor to address its catastrophic effects and safeguard global sustainability.

Graphical Abstract



Schematic presentation of the evolution of global climate change

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Introduction

Over the past 65 years, humanity has witnessed significant global shifts in climate, including observed and projected global warming. These changes present a critical challenge that transcends borders and impacts various aspects of our lives, from the environment to socio-political and socio-economic spheres. The increasing prevalence of rising temperatures worldwide emphasizes the urgent need for immediate action to mitigate the destructive effects of climate change. However, comprehending the full scope of these impacts on different sectors remains intricate, as highlighted by the growing acknowledgment of climatic uncertainties at local and national policymaking levels [1,2]. Tackling this challenge necessitates collaborative efforts and proactive measures to bolster our resilience and adaptability to a changing climate. The discourse surrounding climate change has a longer history than many realize. According to Weart (2007), humanity has grappled with climate change since ancient times. Weart (2007) posits that humans have influenced climate change for centuries, and our understanding of the issue has evolved with technological advancements. Guy Stewart Callendar played a significant role in this historical narrative by raising concerns about the potential implications of carbon dioxide as a heat-trapping agent. Subsequently, computer climate simulations in the 1970s further supported this hypothesis. The monthly average of carbon dioxide levels collected at the Mauna Loa Observatory in Hawaii is the oldest continuous record of direct CO_2 atmospheric observations (Figure 1). C. David Keeling of the Scripps Institution of Oceanography launched this monitoring program in March 1958 at a station run by the National Oceanic and Atmospheric Administration [3-5].

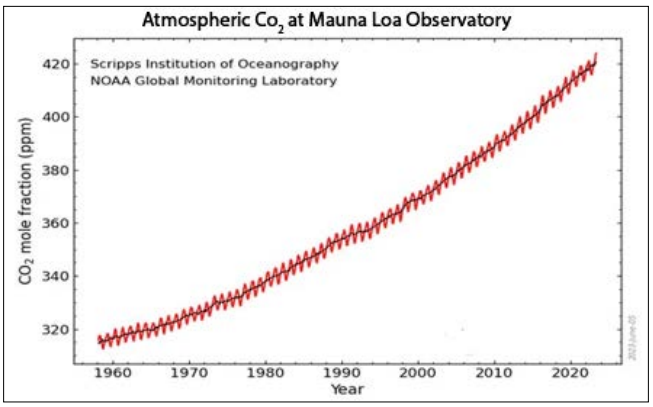

Figure 1: Presentation of the "Keeling Curve". Data was acquired from the NOAA Global Monitoring website, gml.noaa.gov, on June 5, 2023

Despite a minor reduction from 83% in 2019 and 85% five years prior, fossil fuels still accounted for 82% of primary energy use in 2021. It is vital to highlight that fossil fuels, notably coal and gas, remain the primary sources of global electricity production, accounting for more than 60% of the world's electricity supply. This information highlights the critical need for action on climate policy. Failure to address this issue has had and continues to substantially impact the environment and human health [6-8]. These effects include changes in the growth patterns and distribution of plants, animals, and insects, as well as phenomena such as ocean acidification and shifts in marine species distribution to the poles. These changes impact worldwide fisheries. Anthropogenic climate change (ACC) has probably heightened the frequency and severity of daily temperature extremes and contributed to a widespread intensification of daily precipitation extremes. These extreme weather events have raised human disease and mortality rates and prompted forced migration, particularly in disadvantaged countries around the world [9].

Furthermore, accumulating research suggests that extreme weather occurrences are causing increased economic losses, particularly in temperate regions. While troposphere warming is constant, it is unclear if certain extreme weather events such as floods, droughts, and heat waves are largely or fully caused by anthropogenic climate change. This review focuses on climate change's economic effects and its impact on biodiversity.

This review aims to bridge the gap between scientific research and public understanding. In addition, there is a debate on the complex interplay between climate change and other global crises, such as food security, water scarcity, and social injustice, which emphasizes the interconnection of these issues and the importance of integrated solutions. Moreover, the review has provided valuable information on possible adaptation and mitigation techniques to address climate change challenges. By highlighting creative techniques and successful case studies from around the world, the authors still hope and emphasize the need for collaborative efforts in creating a more resilient and sustainable future. The setting of emission targets, introducing carbon pricing mechanisms such as carbon taxes or cap and trade schemes, and promoting low-carbon activities and technologies require policy and legislation to be implemented to control emissions from transport, agriculture, industry, and other sectors. Ecosystem-based Adaptation (EbA) refers to using biodiversity and ecosystem services to help people adapt to the negative effects of climate change. To adapt to changing climate conditions, farmers use a variety of tools. To maintain soil moisture and fertility stability, one instance is the introduction of drought-resistant crop varieties and conservation practices such as no-till farming or crop rotation. Nature-Based Solutions: NBS is another solution that integrates adaptation and mitigation measures, increasing climate resilience while reducing greenhouse gas emissions [9,10].

The review highlights recent scientific advancements and emerging trends in climate research, shedding light on novel insights into the mechanisms driving climatic changes and their cascading impacts on ecosystems, economies, and human societies. By synthesizing this cutting-edge knowledge, the review offers valuable insights for policymakers, researchers, and practitioners seeking to develop effective strategies for mitigating climate change and enhancing resilience to its impacts [11].

Moreover, the review emphasizes the importance of interdisciplinary collaboration and collective action in addressing the global challenge of climate change, underscoring the need for innovative approaches and international cooperation to secure a sustainable future for all. In doing so, it contributes to advancing the climate change adaptation and mitigation discourse, offering a comprehensive framework for informed decision-making and action at local, national, and global levels.

Impact on Biodiversity

Earth's climate system is undergoing unprecedented changes due to our activity, particularly greenhouse gas emissions. These changes take many forms, including increased temperatures, changed precipitation patterns, stronger storms, and sea level rise. Notably, the rate at which these changes occur exceeds natural variability,

providing formidable challenges to ecosystems worldwide. Climate change significantly impacts biodiversity, affecting taxa and ecosystems alike. One notable outcome is the modification of species distributions and phenology. Species are forced to adapt or move to find adequate climatic conditions, which often results in ecological mismatches and the loss of biodiversity hotspots. For instance, the loss of habitat for polar bears owing to melting sea ice reflects the suffering of many Arctic animals. The distribution of any species across geography often relies on its ability to handle environmental challenges, interact with other organisms, and overcome obstacles to dispersal. Local animals must adapt, move, or suffer extinction as conditions change rather than remain static. Few species adapt more quickly to new surroundings, while others struggle to thrive in their existing habitats. Factors such as habitat connectivity and access to varied microclimates are essential in determining a species' resilience to climate change and severe weather events. For instance, variations in worldwide mangrove ranges caused by climate change can impact carbon sequestration rates [12,13].

Similarly, the loss of kelp forests in many places, which seaweed turfs have replaced, has increased herbivory among tropical fish populations. Rising water temperatures push kelp colonies beyond their tolerance. The loss of keystone species poses significant threats to entire ecosystems, with ripple effects on community dynamics. Climate change affects species redistribution indiscriminately, potentially compromising carbon storage and overall ecosystem productivity [14]. These disruptions extend to marine and terrestrial ecosystems, affecting productivity and community composition and producing toxic cyanobacteria blooms. For instance, one study found that rising temperatures caused changes in the makeup of plankton groups. Changes in aquatic producer communities, i.e., diatoms and calcareous plants, now result in biological carbon recycling variations. Furthermore, such alterations are identified as a potential contribution to CO_2 discrepancies between the Pleistocene glacial and interglacial periods. Nature-based solutions, such as habitat restoration and sustainable land management, show promise for slowing biodiversity loss while mitigating climate change. Furthermore, promoting international cooperation and incorporating indigenous knowledge might improve adaptive capacity and allow equitable responses to climate change [15]. The distribution of crops is shifting geographically as climate conditions change. In countries like Ethiopia and Colombia, coffee production is moving to higher altitudes due to the high risk of temperature and rainfall. However, in the long term, it may not be economically viable because of the limited availability of land. Food insecurity, particularly in the areas of vulnerability, is exacerbated by climate change.

Similarly, the decline of kelp forests in various regions, replaced by seaweed turfs, has led to increased herbivory by tropical fish populations. Rising water temperatures further stress kelp communities beyond their tolerance levels. The loss of keystone species poses significant threats to entire ecosystems, with ripple effects on community dynamics. Climate change affects species redistribution indiscriminately, potentially compromising carbon storage and overall ecosystem productivity [16]. These changes, which affect productivity and the composition of ecosystems or even lead to blooms of toxic cyanobacteria, also affect coastal and inland ecosystems. According to the Bank's 2008 report, forests are a major food source for about 1.6 billion people worldwide, and 350 million people, in particular, rely heavily on these sources. Among these, there are 1.2 billion communities dependent on agro-forestry, while 60 million indigenous individuals rely solely on forests and their products for their daily needs.

Climate Change Impacts on the Economic Sectors

This review dives into the substantial consequences of climate change on numerous economic sectors, using relevant instances to demonstrate the importance of tackling this issue:

Agriculture: Climate change enormously complicates agricultural productivity and food security globally. Droughts, floods, and heatwaves affect crop yields, causing farmers to lose money and food prices to skyrocket. For instance, California's prolonged drought, exacerbated by climate change, resulted in significant revenue losses for the agricultural industry of various states, affecting not only local economies but also national food supplies [17].

Energy Sector: Both conventional and renewable energy sources face difficulties due to climate change, which upends systems for producing and delivering energy. For instance, changes in precipitation patterns and glacial melt cause fluctuations in water availability that affect hydropower output, a major renewable energy source. On the other hand, as hurricanes have destroyed refineries along the Gulf Coast, the rising frequency and intensity of storms threaten the infrastructure supporting the oil and gas industry, resulting in disruptions to supply and financial losses.

Insurance and Financial Markets: Global insurance systems and financial markets are under pressure due to climate-related disasters' increasing frequency and intensity. The escalating claims resulting from climate-related incidents like hurricanes, wildfires, and floods are causing insurers to reassess their risk models and premium structures. Furthermore, the effects of climate change have created concerns for the financial markets. Figure 2 lists recent research on how different sectors are affected by climate change and how to mitigate and adapt to it globally [18-20].

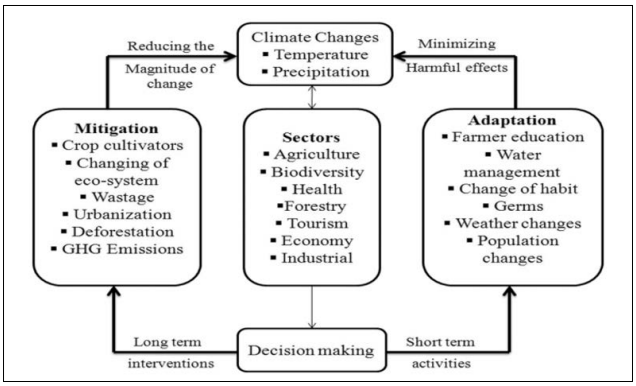

Figure 2: Presentation of impacts of climate change on different sectors and how to mitigate and adapt (Reproduced with permission)

Anthropogenic Influences

Due to the irreversible impacts of climate change on natural environments, scientists, policymakers, and conservationists are now focusing on finding ways to lessen its effects and adapt to them. These efforts are vital for preserving diverse forms of life and safeguarding human existence and quality of life. Evidence of continuing climate change and its effects on the environment and society may be found in several markers. The rise in the world's average temperature over the past century, with each decade being warmer than before, is one important signal. Changes in precipitation patterns are associated with rising temperatures;

in certain areas, these changes take the form of longer droughts and more frequent and intense downpour events. The melting of glaciers and polar ice caps, which raises sea levels and modifies ocean circulation patterns, is another sign. A key indicator of how climate change affects ecosystems is changes in biodiversity, such as shifts in species ranges and phenological occurrences. The main causes of global climate change are human activity, specifically the combustion of fossil fuels, deforestation, and industrial operations. The globe warms as a result of the heightened greenhouse effect caused by the release of greenhouse gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases trap heat in the Earth's atmosphere. Climate change is further exacerbated by changes in land use, such as urbanization and agricultural growth, which modify the Earth's surface albedo and carbon-storing capacity. Anthropogenic greenhouse gas emissions are caused mainly by the extensive use of fossil fuels for industrial activities, transportation, and energy production. Deforestation and land degradation also decrease the Earth to absorb CO_2 through photosynthesis by releasing stored carbon into the atmosphere [20-22].

The indisputable effects of climate change on the natural world have caused scientists, decision-makers, and environmentalists to refocus their efforts on figuring out how to lessen and adjust to these changes. These initiatives are essential for human survival and well-being and for protecting biodiversity. Assisting ecosystems in recuperating from disruptions and adapting to novel situations is crucial to enhancing ecosystem resilience. Promoting biodiversity is important because diversified ecosystems are better able to withstand adversity. Adaptive management is gaining traction as it entails making adaptable decisions in response to the ecosystem's feedback. Modern approaches recognize the importance of ecological corridors that link fragmented habitats, allowing species to move and genes to mix, which is vital for adapting to change. Restoration ecology, including projects like reforestation and wetland rehabilitation, also plays a significant role in lessening the impacts of climate change [23].

The notion of time of emergence was changed to provide decision-makers with additional information. Transient climate response (TCR), which gauges how regional temperatures react to variations in external radiative forcing, can be estimated for each temperature series using ordinary least squares regression, which provides a common long-term trend. The statement above aligns with the well-established linear correlation between radiative forcing and perturbative temperature variations, encompassing regional temperatures except in regions where intense regional impacts of external forcing transpire. Strengthening the ability of ecosystems to recover from disturbances and adapt to new circumstances is a prerequisite for enhancing their resilience. As ecosystems with various species are more resilient to external pressures, promoting biodiversity is an important approach [22-25]. An increasing number of people are adopting adaptive management, which involves staying flexible and adjusting decisions based on environmental feedback. Other strategies to improve resilience include creating green infrastructure in cities and implementing climate-smart farming practices. The core sources of greenhouse gas emissions must be addressed to mitigate climate change, and sustainable development must be encouraged. One such tactic is switching to renewable energy sources, which can drastically lower greenhouse gas emissions from the energy sector and include solar, wind, and hydroelectric power.

Further lowering emissions and boosting energy security can be achieved by increasing energy efficiency in industry, transportation, and buildings. In addition, preserving and replenishing organic ecosystems like wetlands, grasslands, and forests can absorb carbon dioxide from the atmosphere and increase resistance to the effects of climate change. Figure 3 portrays the various strategies for reducing greenhouse gas emissions from land use and agriculture.

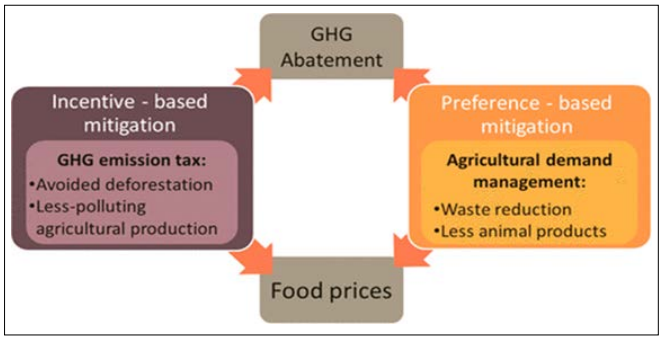

Figure 3: Cyclic presentation of greenhouse gas abatement mitigation strategies (Reproduced with permission)

Today, conservation efforts are not only about the designation of nature reserves. Rather, the focus is on building ecological corridors between fragmented habitats, facilitating the movement of species and the exchange of genetic material, both of which are essential for environmental adaptation. It is also important to restore ecology, with programs such as wetlands restoration and planting contributing to mitigating the effects of climate change [25].

Climate Change vis-à-vis Global Warming

Global warming and climate change are not inseparable, even though they are often used interchangeably in the same language, according to Mann (2009) and Villar & Krosnick (2011). As a result of this misunderstanding, both topics have become part of society's general vocabulary and discussion. Climate change, a term that first appeared in scientific discussions before global warming, refers to human-caused and natural causes that influence climate patterns. As added later, global warming focuses on surface temperature increases caused by greenhouse gas emissions from activities such as fossil fuel burning and focuses on human causes of climate change. People consider global warming more important than a broader, less disturbing concept of climate change because it sounds urgent and uncontrollable. Scientists have significantly advanced in understanding and predicting Earth's climate system, allowing them to estimate future climate changes more confidently.

Nevertheless, accurate forecasts of how global and regional temperatures will vary in the next few decades are hampered by significant problems. For starters, it is hard to predict the precise amount of CO_2 emissions from human activities due to global economic developments and energy use. Second, given the complexity of climate feedback systems, there are a variety of possible outcomes, even for specific CO_2 emission scenarios. Finally, natural climate changes can influence temperature trends over shorter durations, adding to the uncertainty [26]. Despite these challenges, all models point to continued warming of the Earth over the next few decades to centuries.

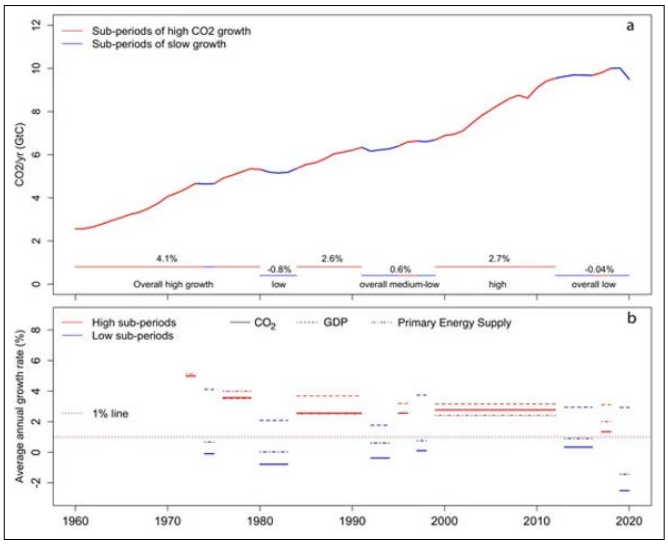

Figure 4: The history of global CO_2 emissions from fossil fuels and industries between 1960 and 2020 reveals unique trends- (a) During this time, there were six stages of fast development in emissions (shown in red), with annual growth rates above 1%. In contrast, there were five stages of slower growth (shown in blue), in which growth rates remained at or below 1%; (b) the average annual increase rates of CO_2 emissions for high and low growth periods (Reproduced with permission)

The Global Carbon Project, World Bank, and IEA data sheds light on the linked dynamics of economic development and energy use. While greenhouse gases are still recognized as key contributors to climate change, the only definite association found is between solar and orbital fluctuations. They believe that human-caused CO_2 emissions cannot be the only cause of climate change because any increase in CO_2 levels is naturally balanced over time. Furthermore, individuals who blame global warming on fossil fuel use are viewed as purposely weakening the world economy, particularly the United States, with the potential to return society to the pre-industrial era [27].

Effect of Abiotic Stresses on Plants

Changes in the environment due to climate change have a significant impact on the growth and yield of plants. These shifts in climate can stress plants in various ways, affecting how well crops perform. Common stresses induced by climate change include higher carbon dioxide (CO_2) levels, increased temperatures, salinity, and drought.

For instance, an increase in CO_2 concentration may affect the structure and functioning of crop plants positively or negatively. Firstly, higher levels of CO_2 may lead to enhanced photosynthesis, support for growth, and increased biomass and yield. The researchers discovered that plants with higher CO_2 levels show increased carbon fixation in photosynthesis, resulting in greater growth and yields [28]. When exposed to elevated CO_2, these compounds are present in rice plants at different growth stages. Studies show rice plants' protein, iron, and zinc content decreases in response to higher atmospheric CO_2 concentrations.

Similarly, researchers found declines in essential nutrients like protein, iron, and zinc in rice crops under elevated CO_2 conditions. Additionally, documented lower levels of phenolic and flavonoid compounds in rice plants at various growth stages when exposed to elevated CO_2. Climate change-induced variations in environmental conditions have a serious impact on plant productivity and yield. Due to changes in their environment, plant stress is created due to these climatic fluctuations and is mainly affected by crop performance. Drought and heat are the main challenges to crop growth in changing climatic conditions. Crop yield is reduced by drought stress, which inhibits the growth, physiology, and development of the plant. Additionally, few researchers noted a decrease in net photosynthesis rate, stomatal conductance, transpiration rate, and chlorophyll content in wheat, resulting in reduced plant yield. Similarly, studies on maize plants showed decreased plant height, leaf size, and stem girth under water-limiting conditions.

Furthermore, temperature extremes pose significant challenges to global crop production. Cold stress leads to sterility and abortion of grains, while high temperatures reduce grain numbers in wheat plants. Cold stress has also notably decreased the photosynthetic CO_2 uptake rate in sorghum plants. Moreover, high temperatures or heat stress cause seed weight and number declines in various cereals and legumes [29-33].

Few instances of the effects of abiotic stressors on crop plants on global climate change:

Drought Stress: Drought stress limits water availability to plants, resulting in stomatal closure, decreased photosynthesis, and lower crop yields. Crops such as maize, wheat, and rice, for instance, have lower yields and are more susceptible to pests and diseases in areas undergoing extended droughts as a result of climate change [34].

Heat Stress: High temperatures can impair plant metabolism, protein denaturation, and membrane integrity, resulting in decreased photosynthesis and reproductive failure. Heat stress severely influences crops such as soybeans, producing diminished seed sets and poorer grain yield, especially during important reproductive periods [35].

Salinity Stress: Increased soil salinity disrupts plants' water intake and ion balance, resulting in osmotic stress and ion toxicity. Crops such as tomatoes and lettuce, for instance, grow and yield less well in areas where irrigation water includes high levels of salts.

Extreme Temperature: Extreme cold or frost occurrences can damage plant tissues, alter cellular processes, and reduce yields, especially in susceptible crops. Frost damage in the early spring can drastically diminish fruit sets and yields in crops such as grapes and apples, affecting the revenues and agricultural production of growers.

CO_2 Levels: Climate change-induced increases in atmospheric CO_2 levels can have an impact on plant physiology, growth, and yield, but responses differ depending on species and environmental conditions Heat stress disrupts plant cells, causing proteins to become unstable, tearing down membranes, and interfering with metabolism. This produces a large number of damaging chemicals known as reactive oxygen species (ROS), which stress out the plants and can cause significant damage, as shown in Figure 5 [36,37].

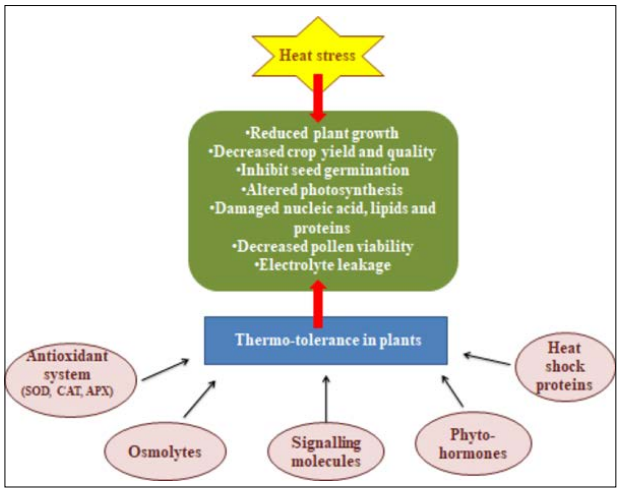

Figure 5: Effect of temperature on the plants' physiological, biochemical, and molecular status (Reproduced with permission)

Food Security

The effects of climate change the world is experiencing are becoming more noticeable, with the possibility of water shortages worldwide and shifts in temperature patterns in the air. Different parts of the world are encountering more extreme weather conditions, such as colder winters, hotter summers, drier deserts, and heavier rainfall and snowfall. Predictions suggest that by 2040 to 2059, temperatures could rise by at least 1 degree Celsius, leading to the melting of ice caps and increased risk of flooding in central regions [38,39]. Climate change has serious implications for global food and energy security; this section describes its impacts and provides a few instances:

Food Security: Crop Yield Reduction: Rising temperatures, shifting precipitation patterns, and severe weather events all impair agricultural production. For instance, in the Sahel region of Africa, persistent droughts have resulted in significant losses in food output, particularly for staple crops such as millet and sorghum. Climate change causes shifts in growing seasons, impacting agricultural growth and productivity. Traditional crops may become unviable in locations where warming is severe, such as the Mediterranean, forcing farmers to switch to new crops or farming practices [40].

Crop Suitability Shifts: The distribution of crops is shifting geographically as climate conditions change. In countries like Ethiopia and Colombia, coffee production is moving to higher altitudes due to the high risk of temperature and rainfall. However, in the long term, it may not be economically viable because of the limited availability of land. Food insecurity, particularly in the areas of vulnerability, is exacerbated by climate change. Rising sea levels in countries pollute freshwater sources, salinize soil, and jeopardize rice production, the country's staple grain. Climate change obstructs energy generation, particularly in countries that rely on hydropower. In the Western United States, for instance, lower snowpack and earlier melting restrict water availability for hydroelectric power generation, compromising energy security.

Impact on Fisheries: Climate change impacts marine ecosystems, resulting in population shifts and dwindling fish stocks. Melting sea ice in the Arctic affects the habitat of animals such as arctic cod, threatening the livelihoods of fishing-dependent indigenous populations.

Renewable Energy Potential and Risks: While climate change impacts existing energy sources, it also creates potential for renewable energy development. Extreme weather events, such as hurricanes and storms, can destroy renewable energy infrastructure, as seen in the destruction of wind turbines in the Gulf Coast region during Hurricane Katrina [41].

Disruptions in the Supply Chain due to Climate Disasters: food and energy systems are interrupted, leading to shortages and price fluctuations. For instance, flooding in Thailand in 2011 interrupted global electronics supply networks, affecting energy-intensive manufacturing companies. Governments and organizations use adaptation and mitigation methods to improve food and energy security in the face of climate change. Precision agriculture technologies that optimize resource utilization and the development of resilient renewable energy systems such as microgrids to assure electricity availability during extreme events are instances of novel techniques.

Adaptation and Mitigation

Adaptation and mitigation are two major tactics used to meet the difficulties provided by global climate change. While adaptation focuses on dealing with the effects of climate change, mitigation seeks to reduce greenhouse gas emissions to minimize future climate change.

In addition to considering how we build and what materials we use, we must ensure that our maintenance routines and road design are prepared to meet the challenges of climate change and any resulting population shifts. Doing so can avoid excessive costs associated with climate change consequences, as shown in Figure 6. Transitioning from fossil fuels to renewable energy sources is critical for combating climate change. Innovative instances include the installation of floating solar farms on reservoirs and using tidal energy to create electricity, hence lowering dependency on carbon-intensive energy sources. Carbon Capture and Storage. Carbon capture and storage devices absorb carbon dioxide emissions from power plants and industrial sites, preventing them from entering the atmosphere. Direct air capture systems extract carbon dioxide directly from the air and are novel approaches to tackling emissions from difficult-to-decarbonize sectors [42]. Promoting sustainable mobility options is also very important in reducing transport emissions. Encouraging the adoption of electric vehicles and developing public transport systems that run on renewable energy is also part of this. In addition, initiatives such as joint mobility services and bike-sharing programs are playing a key role in reducing emissions while making life easier for the community.

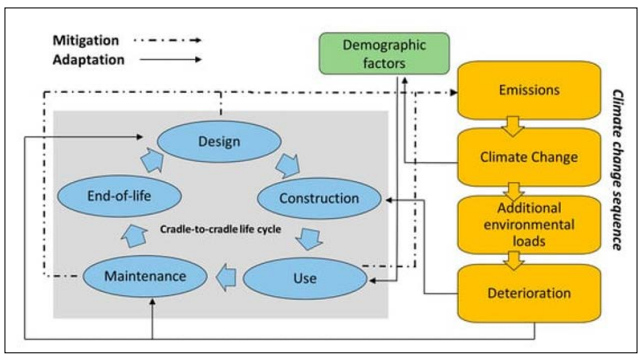

Figure 6: Scheme showing the climate change interaction (Reproduced with permission)

Engaging local communities in adaptation and mitigation initiatives promotes ownership and increases efficacy. Community-led initiatives, such as participatory forest management and community-based renewable energy projects, enable individuals to take collective action to combat climate change while also meeting local development needs. The IPCC (Intergovernmental Panel on Climate Change) report highlights a troubling trend: investment in fossil fuels considerably surpasses investment in climate change mitigation. Despite a 60% increase in public and private funding for climate-related programs since the previous assessment, it is obvious that we are still falling short of the amount required to combat global warming successfully. This disparity is especially noticeable in poorer countries, which are already plagued by debt, low credit ratings, and the fallout from the COVID-19 pandemic. Furthermore, numerous sectors have a substantial funding gap, particularly agriculture, forestry, and land use. Recent financial flows fell 10 to 31 times short of what is required to satisfy the Paris Agreement's targets [41-43].

Enhancing Climate Resilience and Sustainable Development
Nature-Based Solutions for Climate Adaptation

Nature-based solutions (NbS) offer promising avenues for enhancing climate resilience while promoting sustainable development and biodiversity conservation. This shows the concept, benefits, challenges, and policy implications of NbS for climate adaptation [44]. NbS utilizes natural processes and ecosystems to address climate change impacts, offering a range of co-benefits such as flood mitigation, carbon sequestration, and biodiversity enhancement. Drawing on ecosystem services, NbS interventions provide cost-effective alternatives to traditional engineering approaches, fostering ecosystem health and supporting local livelihoods. Case studies from around the world demonstrate the effectiveness of NbS in enhancing community resilience and reducing vulnerability to climate risks. However, scaling up NbS implementation faces challenges related to financing, institutional support, and knowledge gaps. Integrating Indigenous knowledge and fostering stakeholder engagement is crucial for ensuring NbS effectiveness and promoting social equity. Policy support and international cooperation are essential for mainstreaming NbS into climate adaptation strategies and achieving sustainable development goals [45]. The an urgent need for concerted action to leverage nature's resilience in addressing the challenges of climate change while fostering human well-being and environmental sustainability.

Climate-Resilient Infrastructure and Urban Planning

As the impacts of climate change become increasingly apparent, the need for climate-resilient infrastructure and urban planning has become paramount. This part explores the concept, challenges, and strategies of developing infrastructure and urban spaces that can withstand and adapt to changing climatic conditions. Climate-resilient infrastructure encompasses a range of measures, including green infrastructure, sustainable drainage systems, and resilient building design, aimed at minimizing vulnerability to extreme weather events such as floods, heat waves, and storms. Effective urban planning enhances climate resilience by integrating climate considerations into land-use planning, transportation systems, and building codes. This examines the principles of climate-resilient urban planning, including compact and mixed land use, green space preservation, and decentralized infrastructure. Case studies from cities worldwide illustrate innovative approaches to climate-resilient urban development and the benefits of proactive adaptation measures. However, achieving climate resilience in infrastructure and urban areas presents numerous challenges, including financing constraints, competing priorities, and limited technical capacity. Overcoming these challenges requires coordinated efforts among government agencies, private sector stakeholders, and local communities [45,46].

Moreover, integrating social equity considerations into climate-resilient urban planning is essential to ensure that vulnerable populations are not disproportionately affected by climate change impacts. Policy support and regulatory frameworks are critical for mainstreaming climate resilience into infrastructure investment decisions and urban development plans. International cooperation and knowledge sharing can facilitate the exchange of best practices and capacity building among cities facing similar climate challenges. By prioritizing climate-resilient infrastructure and urban planning, communities can build more sustainable, equitable, and resilient cities that are better prepared to face the uncertainties of a changing climate. This shows the importance of proactive adaptation measures and collaborative approaches in building climate-resilient infrastructure and urban spaces, ultimately contributing to urban populations' long-term sustainability and well-being.

Integrating Climate Considerations into Development Policies

As the impacts of climate change continue to intensify, there is a growing recognition of the need to integrate climate considerations into development policies to promote sustainable and resilient outcomes. This examines the strategies, challenges, and opportunities associated with mainstreaming climate considerations across various sectors of development planning. The integration of climate considerations into development policies involves aligning climate change mitigation and adaptation goals with broader development objectives, such as poverty reduction, economic growth, and social equity [47]. This part explores the importance of incorporating climate risk assessments, vulnerability analyses, and scenario planning into policy formulation processes to identify and prioritize adaptation and mitigation measures. Furthermore, effective coordination among government ministries, agencies, and stakeholders is essential for mainstreaming climate considerations into development policies. This shows the role of institutional frameworks, intersectoral coordination mechanisms, and capacity-building initiatives in fostering a climate-responsive policy environment. Case studies from different regions highlight successful integration of climate considerations into development policies, including sustainable land-use planning, energy transition strategies, and disaster risk reduction measures. These case studies demonstrate the benefits of proactive climate action in enhancing resilience, promoting sustainable development, and reducing climate-related risks. However, integrating climate considerations into development policies is not without challenges. Limited financial resources, inadequate technical capacity, and political barriers can hinder progress in mainstreaming climate into policy processes. These challenges require political commitment, stakeholder engagement, and innovative financing mechanisms to support climate-responsive development planning. International cooperation and knowledge sharing are crucial in supporting developing countries' efforts to integrate climate considerations into development policies. This emphasizes the importance of South-South cooperation, North-South collaboration, and multilateral initiatives in facilitating the exchange of best practices, capacity building, and technology transfer. Integrating climate considerations into development policies is essential for building climate-resilient and sustainable societies. By adopting a holistic approach that addresses the interconnected challenges of climate change, development policymakers can promote inclusive, equitable, and environmentally sustainable development pathways.

Promoting Innovation and Technology Transfer

In the face of escalating climate change impacts, promoting innovation and technology transfer has emerged as a critical imperative for enhancing climate resilience across sectors and regions. This explores key strategies, challenges, and pathways for accelerating the adoption and diffusion of innovative technologies to build resilience to climate change. It begins by emphasizing the importance of innovation in developing climate-resilient technologies and solutions. It discusses the role of research and development, private-sector investment, and cross-sectoral collaboration in driving technological innovation for climate resilience [48]. Furthermore, it examines the potential of emerging technologies such as artificial intelligence, remote sensing, and renewable energy to address climate challenges and enhance adaptive capacity. Technology transfer, particularly from developed to developing countries, ensures equitable access to climate-resilient technologies and capabilities. This explores mechanisms for facilitating technology transfer, including international cooperation agreements, public-private partnerships, and capacity-building initiatives. It also highlights the importance of intellectual property rights, technology diffusion strategies, and knowledge sharing platforms in promoting effective technology transfer. Case studies from diverse sectors, such as agriculture, water management, and disaster risk reduction, illustrate successful innovation and technology transfer for climate resilience. These case studies showcase how innovative technologies, such as drought-resistant crops, weather forecasting systems, and early warning systems, can enhance adaptive capacity and reduce vulnerability to climate-related risks [49]. Despite the potential benefits, promoting innovation and technology transfer for climate resilience faces several challenges. Challenges such as financial limitations, institutional obstacles, and a lack of technical expertise in countries receiving assistance hinder progress. Overcoming these hurdles demands joint endeavors involving governments, international bodies, research establishments, and businesses to establish a conducive atmosphere for sharing technology and fostering innovation. Encouraging innovation and technology exchange is crucial for enhancing climate resilience and attaining sustainable development objectives. By nurturing an environment that values creativity, facilitating the sharing of technology, and fostering collaborative relationships, policymakers and stakeholders can unleash the transformative power of technology in addressing climate change issues and shaping a more resilient future for everyone, as illustrated in Table 1.

Table 1: Data on Innovation and Technology Transfer for Climate Change

Aspect	Data	Source
Innovation Impact	- Renewable energy investment grew to USD 1.3 trillion in 2021.	[International Renewable Energy Agency (IRENA)]
	- Climate technologies avoided an estimated 0.8-6 GtCO2 emissions in 2015.	[Intergovernmental Panel on Climate Change (IPCC)]
Technology Transfer Needs	- Developing countries require USD 2.3 trillion annually by 2030 for low-carbon development.	[United Nations Framework Convention on Climate Change (UNFCCC)]
	- 72% of developing countries lack the capacity to implement existing climate technologies.	[UNEP Technology Transfer report]
Transfer Barriers	- High upfront costs for new technologies.	[OECD report on climate innovation]
	- Intellectual property restrictions.	[World Bank report on technology transfer]
Policy Solutions	- Carbon pricing can incentivize low-carbon innovation.	[International Monetary Fund (IMF) research]
	- Technology transfer agreements with capacity-building programs.	[UNFCCC Technology Framework

$GtCO_2$ is a unit measuring greenhouse gas emissions, meaning it contains gigatons of CO_2. USD stands for US Dollars. A look at the positive impact of innovation and the challenges of widespread technology transfer is presented in this table.

Challenges and Opportunities for Global Action

Barriers to Effective Climate Action

Despite growing awareness of the urgent need for climate action, numerous barriers hinder progress towards achieving meaningful and transformative responses to climate change. This overviews the key barriers to effective climate action, examines their underlying causes, and explores potential strategies for overcoming these obstacles. It begins by identifying various barriers to climate action, including political inertia, vested interests, economic challenges, and societal inertia. Political barriers often stem from competing priorities, short-term electoral cycles, and a lack of political will to enact ambitious climate policies. Economic challenges, such as the perceived high costs of mitigation and adaptation measures, can hinder investment in climate-friendly technologies and infrastructure [50].

Moreover, societal inertia and psychological barriers, such as climate skepticism and behavioral inertia, can impede public engagement and support for climate action. Next, delves into the underlying causes of these barriers, including power asymmetries, vested interests, and cognitive biases. Power asymmetries among countries and stakeholders can hinder international cooperation and impede progress in global climate negotiations. Vested interests, particularly in fossil fuel industries, often lobby against climate policies threatening their profitability, perpetuating dependence on carbon-intensive technologies.

Additionally, cognitive biases, such as discounting distant risks and underestimating the severity of climate impacts, can undermine public support for ambitious climate action. We discuss potential strategies for overcoming these barriers and catalyzing transformative climate action. These strategies include enhancing political leadership and governance structures, mobilizing public

support through education and awareness campaigns, and fostering international cooperation and partnerships .

Moreover, incentivizing innovation and investment in low-carbon technologies and integrating climate considerations into financial decision-making processes can help overcome economic barriers to climate action. Case studies and instances of successful initiatives from different sectors and regions illustrate how innovative approaches and collaborative partnerships can overcome barriers to climate action. These instances highlight the importance of adaptive governance, inclusive decision-making processes, and multi-stakeholder engagement in fostering climate-resilient and sustainable societies. Addressing barriers to effective climate action requires a multifaceted approach that addresses political, economic, and societal challenges while fostering collaboration and innovation at local, national, and international levels. By understanding the root causes of these barriers and implementing targeted strategies for overcoming them, policymakers, stakeholders, and communities can accelerate progress toward a more sustainable and resilient future.

Opportunities for Transformative Change

Amidst climate change's daunting challenges, significant opportunities exist for transformative change that can catalyze a transition toward a more sustainable and resilient future [50]. This explores key opportunities across various sectors and domains where transformative action can bring positive outcomes for people and the planet. It begins by highlighting the growing momentum for climate action, driven by increasing public awareness, technological advancements, and evolving policy landscapes. This momentum presents a unique opportunity to accelerate the transition to a low-carbon economy and foster innovation in renewable energy, clean transportation, and sustainable agriculture. Furthermore, this examines opportunities for transformative change in urban planning and infrastructure development. By adopting climate-resilient design principles, promoting green infrastructure, and investing in public transit and active transportation, cities can enhance resilience to climate impacts while improving the quality of life for residents. In addition, it explores opportunities for nature-based solutions (NBS) to address climate change and biodiversity loss simultaneously. Investing in ecosystem restoration, sustainable land management, and conservation initiatives can mitigate greenhouse gas emissions, enhance ecosystem services, and support livelihoods in vulnerable communities.

Moreover, we discuss opportunities for enhancing international cooperation and solidarity in addressing climate change. By mobilizing climate finance, technology transfer, and capacitybuilding support, developed countries can assist developing nations in their efforts to build climate resilience and adapt to the impacts of climate change. Case studies and instances of successful initiatives illustrate how transformative change is already underway in various contexts. These instances demonstrate the potential of community-led initiatives, public-private partnerships, and innovative financing mechanisms to drive positive change and build resilience to climate change. Transformative change offers a pathway toward a more sustainable, equitable, and resilient future in the face of climate change [49-52]. Policymakers, businesses, and civil society can unlock the potential for transformative change and build a better world for current and future generations by seizing opportunities for innovation, collaboration, and collective action.

Role of Public Awareness and Education

Public awareness and education play a pivotal role in driving meaningful climate action and fostering a collective response to the challenges posed by climate change. It was examines the importance of raising public awareness, enhancing climate literacy, and promoting behavioral change to empower individuals and communities to take action on climate change. The begins by highlighting the urgency of addressing climate change and the need for widespread understanding of its impacts, causes, and solutions. It discusses how public awareness campaigns, educational initiatives, and media coverage can help raise awareness about the risks and opportunities associated with climate change, motivating individuals to support climate action. Furthermore, it explores the role of climate education in building climate resilience and promoting sustainable lifestyles. Education can empower individuals with the knowledge, skills, and attitudes needed to adapt to climate change and reduce their carbon footprint by integrating climate change into school curricula, vocational training programs, and lifelong learning initiatives. In addition, it shows the importance of fostering a climate responsibility and civic engagement culture. Education can empower citizens to advocate for climate-friendly policies, support renewable energy initiatives, and engage in community-based climate adaptation and mitigation efforts by providing platforms for dialogue, participation, and collaboration.

Moreover, this examines the potential of digital technologies and social media in disseminating climate information and mobilizing public support for climate action. By leveraging online platforms, interactive tools, and storytelling techniques, educators and communicators can reach diverse audiences and inspire collective action on climate change. Case studies and instances of successful public awareness and education campaigns illustrate how targeted messaging, community engagement, and participatory approaches can effectively raise awareness and mobilize support for climate action. These instances demonstrate the importance of tailoring communication strategies to different audiences and leveraging cultural and social contexts to maximize impact. Public awareness and education are essential pillars of effective climate action, providing the foundation for informed decision-making, behavior change, and collective mobilization. By investing in climate education, fostering dialogue, and leveraging communication technologies, societies can empower citizens to become active agents of change and accelerate progress towards a more sustainable and resilient future.

Conclusions

The evolving global climate stands as one of the most critical challenges of our era, profoundly impacting ecosystems, economies, and the well-being of people worldwide. This thorough review consolidates the current understanding of the factors driving, the signs of, and the outcomes resulting from these changes. We delve into the intricate interplay between human activities, natural variations, and feedback loops that steer alterations in temperature, rainfall patterns, sea levels, and extreme weather occurrences. Notably, our research underscores the undeniable influence of human actions, particularly the release of greenhouse gases from fossil fuel combustion and land modifications, in propelling the unprecedented warming rates witnessed in the last century. These changes manifest diversely, from melting polar ice caps and rising sea levels to shifts in rainfall patterns and the intensification of extreme weather events like hurricanes, droughts, and heatwaves.

Furthermore, we analyze the cascading effects of climate changes on ecosystems, biodiversity, agriculture, water supplies, human health, and socio-economic structures. Varied vulnerabilities and impacts are evident across regions, with disadvantaged communities,

coastal areas at risk of flooding, and developing countries facing amplified threats and limited adaptive capabilities. Leveraging recent scientific progress, we explore strategies for mitigation and adaptation aimed at reducing greenhouse gas emissions, bolstering resilience, and fostering sustainable progress. These strategies encompass transitioning to renewable energy sources, adopting nature-based solutions, enhancing climate resilience in infrastructure and urban design, and advocating for international collaboration and policy frameworks. By amalgamating diverse viewpoints from climate science, ecology, economics, and social sciences, this review emphasizes the urgent call for ambitious and collective global efforts to mitigate climate change, protect ecosystems, and ensure a sustainable future for all. Addressing the multifaceted challenges posed by global climate shifts necessitates interdisciplinary teamwork, innovation, and shared dedication at local, national, and international levels.

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References

1. Arias KS, Velty A, Climent MJ, Iborra S (2024) Valorization of biomass platform molecules through one-pot cascade processes using heterogeneous catalysts. In Tetrahedron Green Chem 3: 100037.
2. Bhattacharjee J, Roy S (2024) Utilizing a Variable Material Approach to Combat Climate Change. In Material Science Research India 20: 141-145.
3. Ravishankara AR, Rudich Y, Pyle JA (2015) Role of Chemistry in Earth's Climate. In Chemical Reviews 115: 3679-3681.
4. Suresh Kumar R, Arumugam N, Murugesan Senthil Kumar S (2024) Construction of Heteroatom-Doped Porous Carbon Architectures for Energy and Sensing Applications. In Nanotechnology and Nanomaterials. Intech Open https://doi.org/10.5772/intechopen.114079.
5. Amoo CC, Orege JI, Ge Q, Sun J (2023) Exploiting the latency of carbon as a catalyst in CO_2 hydrogenation. In Chemical Engineering Journal 471: 144606.
6. Gabric AJ (2023) The Climate Change Crisis: A Review of Its Causes and Possible Responses. In Atmosphere 14: 1081.
7. Clark WC, Harley AG (2020) Sustainability Science: Toward a Synthesis. In Annual Review of Environment and Resources 45: 331-386.
8. Coronese M, Lamperti F, Keller K, Chiaromonte F, Roventini A (2019) Evidence for a sharp increase in the economic damages of extreme natural disasters. In Proceedings of the National Academy of Sciences 116: 21450-21455.
9. Garg R, Anjum A (2024) Smart and Sustainable Applications of Nanocomposites. In Advances in Chemical and Materials Engineering https://books.google.co.in/books?hl=en&lr=&id=rtzzEAAAQBAJ&oi=fnd&pg=PR1&dq=Smart+and+Sustainable+Applications+of+Nanocomposites.+In+Advances+in+Chemical+and+Materials+Engineering&ots=wy2uoFCrn1&sig=G7RQPfRp-RBaa-bgA9srKura770#v=onepage&q=Smart%20and%20Sustainable%20Applications%20of%20Nanocomposites.%20In%20Advances%20in%20Chemical%20and%20Materials%20Engineering&f=false.
10. Bhattacharjee J, Roy S (2024) Review on green resources and AI for biogenic solar power [Online]. Energy Storage and Conversion https://ojs.acad-pub.com/index.php/ESC/article/view/457.
11. De A, Bhattacharjee J, Chowdhury SR, Roy S (2023) A Comprehensive Review on Third-Generation Photovoltaic Technologies. In Journal of Chemical Engineering Research Updates 10: 1-17.
12. Bhattacharjee J, Roy S (2023) Biogenic Electrodes for Low-Temperature Solid Oxide Fuel Cells. In ECS Meeting Abstracts 40: 2805-2805.
13. Mazumder SK, De M, Mazlan AG, Zaidi CC, Rahim SM, et al. (2014) Impact of global climate change on fish growth, digestion and physiological status developing a hypothesis for cause and effect relationships. In Journal of Water and Climate Change 6: 200-226.
14. 1Liu HT, Xiong XG, Diem Dau P, Wang YL, Huang DL, et al. (2013) Probing the nature of gold–carbon bonding in gold–alkynyl complexes. In Nature Communications 4.
15. Shakun JD, Clark PU, He F, Marcott SA, Mix AC, et al. (2012) Global warming was preceded by increasing carbon dioxide concentrations during the last deglaciation. In Nature 484: 49-54.
16. Simmer RA, Jansen EJ, Patterson KJ, Schnoor JL (2023) Climate Change and the Sea: A Major Disruption in Steady State and the Master Variables. In ACS Environmental Au 3: 195-208.
17. Zhang J, Peng J, Hu D, Xu C, Lan Z (2022) Understanding photolysis of CH3ONO2 with on-the-fly nonadiabatic dynamics simulation at the ADC(2) level. In Chinese Journal of Chemical Physics 35: 451-460.
18. Debnath S, Jena C, Ghude SD, Kumar R, Govardhan G, et al. (2022) Simulation of Indian Summer Monsoon Rainfall (ISMR) with fully coupled regional chemistry transport model: A case study for 2017. In Atmospheric Environment 268: 118785.
19. Abbass K, Qasim MZ, Song H, Murshed M, Mahmood, et al. (2022) A review of the global climate change impacts, adaptation, and sustainable mitigation measures. In Environmental Science and Pollution Research 29: 42539-42559.
20. Zhu Y, Li W, Huang Y, Zheng Y, Wang D, et al. (2020) Catalytic pyrolysis of cellulose over solid acidic catalysts: an environment-friendly method for furan production. In Biomass Conversion and Biorefinery 11: 2695-2702.
21. Zhao XG, Yang JH, Fu Y, Yang D, Xu Q, et al. (2017) Design of Lead-Free Inorganic Halide Perovskites for Solar Cells via Cation-Transmutation. Journal of the American Chemical Society 139: 2630-2638.
22. Choi Y, Zhang N, Zhou P (2012) Efficiency and abatement costs of energy-related CO_2 emissions in China: A slacks-based efficiency measure. In Applied Energy Elsevier BV 98: 198-208.
23. Elobeid A, Moreira MMR, Zanetti de Lima C, Carriquiry M, Harfuch L (2019) Implications of biofuel production on direct and indirect land use change: Evidence from Brazil. In Biofuels Bioenergy and Food Security Elsevier 125-143.
24. Stevanović M, Popp A, Bodirsky BL, Humpenöder F, Müller C, et al. (2016) Mitigation Strategies for Greenhouse Gas Emissions from Agriculture and Land-Use Change: Consequences for Food Prices. In Environmental Science Technology American Chemical Society (ACS) 51: 365-374.
25. Dietrich JP, Bodirsky BL, Humpenöder F, Weindl I, Stevanović M, et al. (2019) MAgPIE 4 – a modular open-source framework for modeling global land systems. In Geoscientific Model Development Copernicus GmbH 12: 1299-1317.

26. Secretariat UNFCCC (2021) Nationally determined contributions under the Paris Agreement-Synthesis report by the secretariat. In Proceedings of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement Third session 31: 6-18.
27. Pedersen JST, van Vuuren DP, Aparício BA, Swart R, Gupta J, et al. (2020) Variability in historical emissions trends suggests a need for a wide range of global scenarios and regional analyses. In Communications Earth Environment. Springer Science and Business Media LLC https://www.nature.com/articles/s43247-020-00045-y.
28. 28. Westerling AL, Hidalgo HG, Cayan DR, Swetnam TW (2006) Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity. In Science. American Association for the Advancement of Science (AAAS) 313: 940-943.
29. Bhattacharjee J, Roy S (2023) Green Remediation of Microplastics Using Bionanomaterials. In Remediation of Plastic and Microplastic Waste CRC Press 240-260.
30. Keeling CD (1960) The Concentration and Isotopic Abundances of Carbon Dioxide in the Atmosphere in Tellus A: Dynamic Meteorology and Oceanography. Stockholm University Press 12: 200-203.
31. Fischer EM, Sippel S, Knutti R (2021) Increasing probability of record-shattering climate extremes In Nature Climate Change. Springer Science and Business Media LLC 11: 689-695.
32. 32. Intergovernmental Panel on Climate Change (2015) Climate Change 2014: Mitigation of Climate Change. Cambridge University Press https://www.cambridge.org/core/books/climate-change-2014-mitigation-of-climate-change/81F2F8D8D234727D153EC10D428A2E6D.
33. O'Riordan T, Lenton T (Eds.) (2013) Addressing Tipping Points for a Precarious Future. British Academy https://academic.oup.com/british-academy-scholarship-online/book/14287.
34. Lenton TM, Rockström J, Gaffney O, Rahmstorf S, Richardson K, et al. (2019) Climate tipping points-too risky to bet against. In Nature Springer Science and Business Media LLC 575: 592-595.
35. 35. Downie C (2020) Strategies for Survival the International Energy Agency's response to a new world. In Energy Policy Elsevier BV 141: 111452.
36. Krueger P, Sautner Z, Starks LT (2020) The Importance of Climate Risks for Institutional Investors. In A. Karolyi (Ed.), The Review of Financial Studies 33: 1067-1111.
37. Jabareen Y (2015) City planning deficiencies climate change – The situation in developed and developing cities. In Geoforum 63: 40-43.
38. Temperton VM, Buchmann N, Buisson E, Durigan G, Kazmierczak Ł, et al. (2019) Step back from the forest and step up to the Bonn Challenge: how a broad ecological perspective can promote successful landscape restoration. In Restoration Ecology 27: 705-719.
39. Strassburg BBN, Iribarrem A, Beyer HL, Cordeiro CL, Crouzeilles R, et al. (2020) Global priority areas for ecosystem restoration. In Nature 586: 724-729.
40. McQueen N, Psarras P, Pilorgé H, Liguori S, He J, et al. (2020) Cost Analysis of Direct Air Capture and Sequestration Coupled to Low-Carbon Thermal Energy in the United States. In Environmental Science Technology 54: 7542-7551.
41. Geyer R, Jambeck JR, Law KL (2017) Production, use, and fate of all plastics ever made. In Science Advances 3.
42. Bhattacharjee J, Roy S (2024) Density Functional Waltz: Molecular Theory of Spin Dynamics. In Journal of Physi; Optics Sciences (1–4). Scientific Research and Community Ltd 6: 1-4.
43. Callahan CW, Dominy NJ, DeSilva JM, Mankin JS (2023) Global Warming, Home Runs, and the Future of America's Pastime. In Bulletin of the American Meteorological Society 104: 1006-1016.
44. Moncada S, Nguyen L (2024) Improving Sustainability, Climate Resilience and Pandemic Preparedness in Small Islands: A Systematic Literature Review. In Sustainability 16: 550.
45. Liu HY, Jay M, Chen X (2021) The Role of Nature-Based Solutions for Improving Environmental Quality, Health and Well-Being. In Sustainability 13: 10950.
46. Thorn JPR, Biancardi Aleu R, Wijesinghe A, Mdongwe M, Marchant RA, et al. (2021) Mainstreaming nature-based solutions for climate resilient infrastructure in peri-urban sub-Saharan Africa. In Landscape and Urban Planning 216: 104235.
47. Bird G (1996) The International Monetary Fund and developing countries: a review of the evidence and policy options. In International Organization 50: 477-511.
48. Matos S, Viardot E, Sovacool BK, Geels FW, Xiong Y (2022) Innovation and climate change: A review and introduction to the special issue. In Technovation 117: 102612.
49. Santos FD, Ferreira PL, Pedersen, JST (2022) The Climate Change Challenge: A Review of the Barriers and Solutions to Deliver a Paris Solution. In Climate 10: 75.
50. Sovacool BK, Hess DJ, Amir S, Geels FW, Hirsh R, et al. (2020) Sociotechnical agendas: Reviewing future directions for energy and climate research. In Energy Research & Social Science 70: 101617.
51. 51. Mebane M E, Benedetti M, Barni D, Francescato D (2023) Promoting Climate Change Awareness with High School Students for a Sustainable Community. In Sustainability 15: 11260.
52. Shaikh Abdul A, Jyoti Bhattacharjee, Preetam Datta, Subhasis Roy (2024) A Comprehensive Review of the Oxidation States of Molybdenum Oxides and Their Diverse Applications. Sustainable Chemistry for the Environment 7: 100125.