Climate Change, Economic Growth, and Environmental Policy: A Survey

www.surveyx.cn

Abstract

This survey paper explores the intricate interplay between climate change, economic growth, and environmental policy, highlighting their interconnectedness and the multifaceted challenges they present. It categorizes existing research into major subfields, providing a framework for understanding climate change's evolution and its socioeconomic impacts. Key findings emphasize the significant role anthropogenic activities play in exacerbating climate change, manifesting in phenomena such as global warming and altered precipitation patterns, which threaten food security and agricultural productivity. The paper underscores the importance of environmental policies and the transition to clean energy in mitigating adverse effects. Integrated Assessment Models (IAMs) are highlighted for addressing climate uncertainty, guiding policy decisions, and fostering sustainable development. The survey methodically examines the impacts of climate change on economic productivity, emphasizing the necessity for adaptive strategies in agriculture, energy, and urban infrastructure. It also evaluates the role of international agreements and national policies in promoting sustainability. Technological innovations and interdisciplinary approaches are presented as vital for enhancing emission reduction strategies and informing comprehensive climate policy frameworks. The paper concludes by identifying challenges and future research directions, advocating for dynamic, integrated approaches to effectively combat climate change and promote resilience and sustainability.

1 Introduction

1.1 Overview of Interconnected Elements

The interplay among climate change, economic growth, and environmental policy represents a complex challenge for contemporary societies. The survey by [1] categorizes research into key subfields, including continental biomass, climate modeling, and adaptation/mitigation, providing a framework for understanding climate change research evolution. Anthropogenic activities significantly exacerbate climate change, evidenced by global warming and rising sea levels, necessitating innovative detection and quantification methods. The recent increase in global average temperatures illustrates the relationship between climate change and economic growth, as economic activities often intensify environmental issues through elevated greenhouse gas emissions. Urbanization further complicates this relationship by straining environmental resources and increasing the demand for urban cooling [2].

Environmental policies play a crucial role in mitigating the negative impacts of economic activities on the climate. The transition to clean energy, characterized by sustainability and reduced environmental impact, is vital for aligning economic growth with environmental objectives [3]. Government regulation is essential, as market mechanisms alone frequently fall short in addressing climate change [4]. In agriculture, integrating technological solutions with social sciences is critical for addressing climate change's effects on production [5]. The significant impacts of climate change on agriculture,

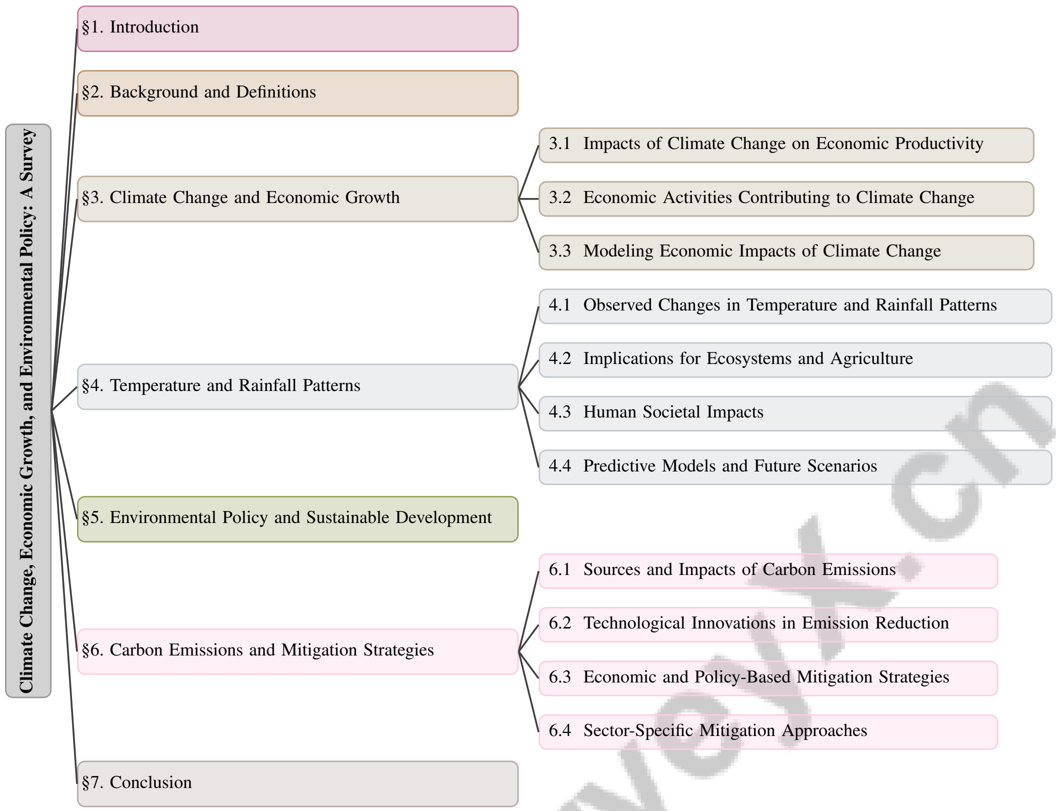


Figure 1: chapter structure

such as rising temperatures and altered precipitation patterns, threaten food security and productivity [6].

The interconnectedness of these elements is further highlighted by the complex dynamics of climate variables. Climate-induced human migrations, driven by extreme events like floods and storms, illustrate the increasing frequency of such occurrences and their socioeconomic implications [7]. The redistribution of biodiversity due to climate change affects both ecosystems and human well-being, emphasizing the link between ecological systems and human societies [8]. Additionally, temperature influences the stability of clay slopes, particularly concerning climate change and its effects on natural hazards such as landslides [9].

Integrated Assessment Models (IAMs) address climate uncertainty and its effects on emissions pathways and the social cost of carbon, underscoring the necessity for robust models to inform policy decisions. Understanding the synergies and conflicts among these elements is crucial for developing policies that promote sustainable development while mitigating climate change impacts. As the effects of climate change on infrastructure and societal systems become increasingly apparent, integrating adaptation and mitigation strategies into investment planning is vital for resilience against extreme weather events. Recognizing the interconnected nature of human activities and climate variables is essential for effective climate change detection and attribution. The complexities of climate policy and the motivations of involved actors highlight the importance of understanding the nature and structure of the climate debate [10].

1.2 Importance of Understanding Dynamics

Grasping the dynamics between climate change and economic factors is essential for devising strategies that balance environmental sustainability with economic growth. The rapid expansion of climate change research, as noted by [1], emphasizes the complexity and volume of literature that researchers must navigate to extract meaningful insights. The uncertainty surrounding future climate scenarios complicates proactive adaptation efforts, particularly in infrastructure financing, where long-term investments must account for unpredictable climate impacts [11]. This uncertainty

AI-generated, for reference only.

is exacerbated by the intricate interactions between land and atmospheric conditions, challenging the development of effective management strategies for hydroclimatic variables [12].

In urban environments, accurately modeling interactions with atmospheric conditions under changing climate scenarios poses significant challenges [13]. This difficulty underscores the necessity for comprehensive data integration, exemplified by the mapping of the STI ecosystem related to Climate Action in Denmark, which highlights the importance of open data for effective policymaking [14]. These insights are critical for formulating policies that not only promote sustainable development but also enhance resilience and adaptation in the face of climate uncertainties. By aligning economic growth with environmental and social objectives, policymakers can maintain economic stability while addressing the pressing challenges posed by climate change.

1.3 Structure of the Survey

This survey is meticulously structured to explore the intricate relationships among climate change, economic growth, and environmental policy, providing an in-depth analysis of their interactions and influences. It underscores the necessity of understanding the economic implications of climate mitigation strategies, the role of financial dynamics in fostering innovation, and the importance of government involvement in addressing the multifaceted challenges posed by climate change across various sectors, including agriculture, health, and tourism [15, 4, 1, 16, 17]. The paper commences with an introduction that establishes the significance of these interactions and the need for integrated approaches to address them. Following the introduction, Section 2 delves into the background and definitions of core concepts, laying a foundational understanding of climate change, economic growth, temperature, rainfall, environmental policy, sustainable development, and carbon emissions.

Section 3 investigates the complex relationship between climate change and economic growth, concentrating on the impacts of climate change on economic productivity, the contributions of economic activities to climate change, and the models employed to predict economic impacts. This section emphasizes the importance of understanding these dynamics for formulating effective mitigation strategies, as highlighted by [18].

In Section 4, the paper analyzes alterations in temperature and rainfall patterns due to climate change and their implications for ecosystems, agriculture, and human societies. This section also reviews predictive models and future scenarios, offering insights into potential changes and their socioeconomic impacts. The correlation between global temperature and sea level, as well as the importance of maintaining temperatures within preindustrial ranges to preserve current shorelines, is emphasized by [19].

Section 5 provides a comprehensive evaluation of the effectiveness of various environmental policies in mitigating climate change and promoting sustainable development, drawing on global efforts and contrasting the diverse approaches adopted by developed and developing nations. It highlights the necessity for a holistic climate policy framework, informed by diverse stakeholder perspectives and enhanced by innovative methodologies such as Natural Language Processing (NLP) to analyze public sentiment and support for climate initiatives [20, 21, 22]. This section discusses international agreements, national policies, and interdisciplinary approaches, emphasizing the collaborative efforts required to address climate challenges effectively.

The analysis of carbon emissions and mitigation strategies is presented in Section 6, identifying major sources of emissions and discussing technological, economic, and policy-based approaches to mitigation. This section also explores sector-specific strategies, highlighting the need for targeted interventions to effectively reduce emissions.

Finally, Section 7 concludes the survey by summarizing key findings and reflecting on the interconnectedness of climate change, economic growth, and environmental policy. The article emphasizes the multifaceted challenges posed by climate change, including its detrimental effects on agriculture, biodiversity, and public health, while underscoring the need for targeted research to develop effective adaptation and mitigation strategies that enhance resilience and sustainability across various sectors [1, 22, 17].The following sections are organized as shown in Figure 1.

2 Background and Definitions

2.1 Defining Climate Change and Its Impacts

Climate change encompasses long-term shifts in temperature and weather patterns primarily driven by human activities, including industrial emissions, deforestation, and agriculture, which elevate atmospheric levels of carbon dioxide and methane. These activities intensify the greenhouse effect, altering temperature and precipitation patterns and increasing extreme weather events' frequency and severity. The connection between climate change and natural disasters necessitates improved disaster preparedness and resource allocation [9].

A critical concern is the potential destabilization of the Atlantic Meridional Overturning Circulation (AMOC), identified as a climate tipping point with significant global consequences. General Circulation Models (GCMs) face challenges in accurately representing low cloud cover impacts, complicating climate sensitivity estimations vital for future projections [12]. Differentiating between natural and anthropogenic climate change causes further complicates this issue.

The effects of climate change are far-reaching, affecting both environmental systems and human societies. In agriculture, it poses risks, particularly in developing nations, decreasing productivity, raising food prices, and exacerbating inequalities. Urbanization amplifies these impacts, necessitating effective local mitigation modeling. Urban areas, major contributors to global GDP and CO2 emissions, face challenges like urban heat islands and extreme heat events, requiring strategic urban cooling measures [14].

Ecologically, climate change alters biodiversity and ecosystem services, directly impacting human health and livelihoods. The concept of entomogenic climate change highlights expanding insect populations' role in accelerating deforestation, worsening climate change by increasing tree mortality and decomposition, reducing carbon sequestration, and enhancing emissions from decaying biomass. This feedback loop intensifies climate effects, threatening critical forest carbon pools. Current research and pest management strategies are insufficient, necessitating innovative monitoring and control methods to mitigate insect-induced deforestation's impact on global climate dynamics [23, 24, 1, 25, 26]. Although positive ecological tipping points are underexplored, they may enhance climate resilience. Additionally, climate change affects vector-borne disease distribution, as seen in the spread of disease-carrying mosquitoes.

Financial frictions complicate optimal carbon tax and abatement level determination, as abatement cost distribution affects carbon pricing efficiency. Infrastructure resilience is increasingly threatened by extreme weather events, emphasizing the need for accessible, reliable climate projections to inform infrastructure planning and investment. These projections help assess vulnerabilities and develop adaptive strategies, such as enhancing capacity and integrating renewable energy sources. For instance, a probabilistic resilience assessment framework can quantify localized weather disruptions' impacts on systems like transportation, while power system models suggest significant renewable energy capacity increases may be necessary to address climate impacts. Such insights are critical for ensuring infrastructure resilience against future climate challenges [18, 22, 27, 28]. Addressing climate change impacts requires an integrated approach combining technological innovations, policy frameworks, and adaptive strategies across various sectors. The socio-economic dimensions of climate change, including environmentally driven mass migration, necessitate robust causal models to assess impacts on social infrastructure and public services.

2.2 Socioeconomic Dynamics and Climate Change

The intricate relationship between socioeconomic factors and climate change significantly influences policy-making and adaptation strategies. Socioeconomic activities, especially in agriculture and urban development, are pivotal to the global economy but also substantially contribute to greenhouse gas emissions. The long-term distributive impacts of climate change, particularly rising food prices, underscore the need to understand agricultural productivity losses, especially in developing regions where food security is crucial [29]. These challenges are compounded by the complexities of biological responses to climate change and interactions with other human activities, complicating specific impact attribution [30].

Climate change's socio-economic consequences are further exemplified by alterations in the hydrological cycle and atmospheric circulation, affecting various socioeconomic factors [31]. Regional

AI-generated, for reference only.

impacts necessitate tailored negotiation strategies to address specific vulnerabilities [2]. The lack of a unified interdisciplinary approach, particularly in sectors like green hydrogen production, highlights the need to integrate land eligibility, renewable energy potential, and socio-economic impacts for effective climate action [3].

Public discourse on climate change is often shaped by ideological positions and misinformation, which significantly influence public support for mitigation policies [32]. The limitations of models like the RICE-N in representing climate change's economic impacts illustrate the challenges in integrating scientific insights with policy frameworks [33]. Moreover, the complexity within integrated assessment models (IAMs) necessitates a more realistic representation of climate change's socio-economic dimensions [1].

Addressing these challenges requires comprehensive strategies connecting climate research with practical innovation. This involves scientific advancements and robust frameworks that account for socioeconomic dynamics' diverse and interconnected elements. By incorporating insights from economic analysis, particularly regarding financial sectors' dynamics and innovation diffusion, into policy-making, socio-economic systems can enhance resilience and adaptability to climate change's complex challenges, including significant emissions reductions and associated economic risk management [28, 34, 16].

In examining the intricate interplay between climate change and economic growth, it is essential to consider the various dimensions that characterize this relationship. The analysis reveals significant impacts on economic productivity, as well as the contributions of economic activities to climate change. To elucidate this complex interaction, Figure 2 provides a comprehensive visual representation. This figure illustrates the hierarchical structure of the relationship between climate change and economic growth, categorizing the impacts on economic productivity, the contributions of economic activities to climate change, and the modeling of economic impacts. It highlights the sectors affected by climate change, the activities contributing to it, and the advanced methodologies used to model these impacts. By integrating this visual framework, we can better understand the multifaceted nature of the challenges posed by climate change to economic systems.

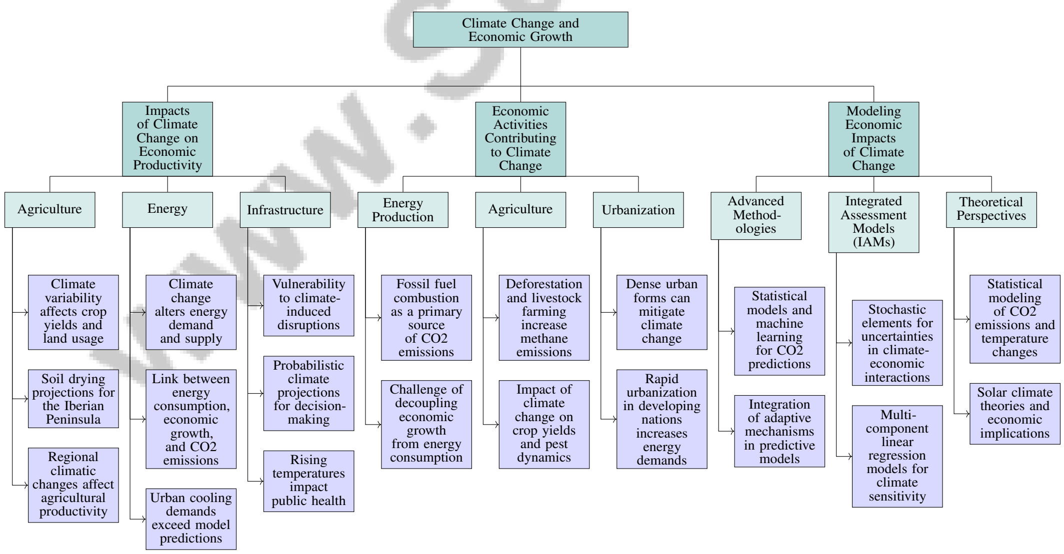


Figure 2: This figure illustrates the hierarchical structure of the relationship between climate change and economic growth, categorizing the impacts on economic productivity, the contributions of economic activities to climate change, and the modeling of economic impacts. It highlights the sectors affected by climate change, the activities contributing to it, and the advanced methodologies used to model these impacts.

AI-generated, for reference only.

3 Climate Change and Economic Growth

3.1 Impacts of Climate Change on Economic Productivity

Climate change significantly affects economic productivity across agriculture, energy, and infrastructure sectors. In agriculture, climate variability, characterized by extreme temperatures and irregular precipitation, directly impacts crop yields and land usage. For instance, projections for the Iberian Peninsula indicate substantial soil drying by the century's end, particularly in summer and fall, affecting water resources and temperature dynamics [12]. The regional variability in climate-related damages necessitates a careful evaluation of economic impacts [35]. The Amazon rainforest's evolving connectivity with the global climate system illustrates how regional climatic changes can propagate, influencing agricultural productivity and ecosystem stability [36].

The energy sector faces similar challenges, as climate change alters both demand and supply. The link between energy consumption, economic growth, and CO2 emissions complicates efforts to decouple these elements [37]. Urban areas, particularly in warmer climates, are experiencing heightened cooling demands that exceed model predictions, emphasizing the need for energy efficiency tailored to specific climatic conditions [27]. Small shifts in carbon emissions can lead to significant climate changes, underscoring the necessity to moderate greenhouse gas emissions [38]. Historical climate data revealing the sensitivity of climate systems to CO2 changes is crucial for informing current climate models and energy policies [39].

Infrastructure systems are particularly vulnerable to climate-induced disruptions, making their resilience vital for economic productivity [27]. Probabilistic climate projections, such as those from AIRCC-Clim, enhance decision-making by providing insights into climate impacts on infrastructure and economic systems [40]. Rising temperatures also reduce the incubation period for pathogens in mosquitoes, highlighting climate change's broader implications for public health and economic stability [41].

Addressing climate change's economic impacts requires an integrated approach that combines predictive modeling, adaptive strategies, and robust policy frameworks. This integration is essential for sectors to adapt while maintaining economic stability. Increased uncertainty regarding climate impacts can lead to costly over- or under-investment in adaptation measures, necessitating coordinated global efforts to mitigate these effects [11]. As urban systems grow in complexity, the integration of large datasets from local to global scales becomes vital [13]. Comprehensive methodologies that incorporate land eligibility, renewable energy simulations, groundwater assessments, and socio-economic indicators are essential for analyzing the cost potentials of green hydrogen and other sustainable solutions [3].

3.2 Economic Activities Contributing to Climate Change

Economic activities, particularly in energy production, agriculture, and urbanization, are significant contributors to climate change due to their substantial greenhouse gas emissions. Fossil fuel combustion for energy and transportation remains a primary source of carbon dioxide emissions. The challenge of decoupling economic growth from energy consumption and CO2 emissions is highlighted by the paradox that efficiency improvements can lead to increased emissions when cheaper, high-emission technologies replace costlier low-emission alternatives. Human activities' influence on carbon emissions underscores the need for sustainable practices [38].

In agriculture, deforestation and livestock farming contribute significantly to methane and nitrous oxide emissions. Climate change profoundly impacts agriculture, affecting crop yields and pest dynamics. The financial implications for farmers remain under-researched, emphasizing the urgent need for comprehensive assessments that explore how agricultural activities contribute to climate change and are affected by its impacts, such as rising temperatures and increased pest infestations, which threaten global food security [25, 42]. Traditional large-scale computational models often fail to capture the complex interactions between the Amazon and the climate system amid rapid environmental changes.

Urbanization influences climate change dynamics in contrasting ways. In developed countries, denser urban forms and improved connectivity can mitigate climate change by lowering transport emissions. Conversely, rapid urbanization in developing nations exacerbates climate challenges by increasing energy demands for cooling and transportation, leading to higher greenhouse gas emissions.

Factors such as urban heat islands necessitate urgent energy efficiency measures and sustainable urban planning to address climate change's adverse effects. Furthermore, urban infrastructure design significantly impacts transport-related emissions, highlighting the need for tailored policies promoting sustainability in rapidly growing cities [43, 44, 45, 46]. Research demonstrates significant advancements in understanding urban heat impacts and their correlation with temperature trends.

The insurance industry can play a role in addressing economic activities contributing to climate change through innovative strategies, such as an insurance-led levy on fossil-fuel producers. This underscores the importance of integrating diverse datasets—geo-climatic, economic, and social—to develop precise predictive models that guide resource allocation and disaster preparedness in the face of increasing extreme weather events. Statistical methodologies and comprehensive data analysis can reveal correlations between climate change and disaster occurrences, enhancing risk management and response strategies [47, 28, 48].

Tourism also contributes to climate change through carbon emissions and resource consumption, necessitating low-carbon tourism strategies. A comprehensive strategy integrating technological innovations, advanced data analytics, and interdisciplinary research is essential for addressing the contributions of economic activities to climate change. This approach facilitates informed policy-making and practical solutions that promote sustainable development while mitigating climate change's adverse impacts. Leveraging techno-economic analyses for energy projects, fostering collaboration among governments, businesses, and researchers, and utilizing tools like Natural Language Processing for sustainability reporting can enhance understanding and management of the complex interplay between economic growth, environmental stewardship, and climate resilience [49, 22, 16]. Such strategies are vital for promoting sustainable economic growth and effectively mitigating climate change impacts.

3.3 Modeling Economic Impacts of Climate Change

Modeling the economic impacts of climate change requires a nuanced understanding of the interactions between environmental and economic systems. Traditional models often struggle to capture the complexities of climate-economic interactions near critical thresholds. Advanced methodologies, including statistical models and machine learning techniques, have been developed to enhance the accuracy of CO2 emission predictions and provide deeper insights into emission trends [50]. This dual-phase approach allows for comprehensive analysis of emission patterns and their economic implications.

The IMPACT model exemplifies innovative simulation tools predicting economic impacts by examining neighborhood-level emissions influenced by zoning policies and technology adoption [43]. This model highlights the significance of local factors in shaping broader economic outcomes related to climate change. Integrating adaptive mechanisms and real-time feedback loops into predictive models has shown promise in improving the reliability of economic impact assessments [51].

Incorporating stochastic elements into Integrated Assessment Models (IAMs), such as the DICE model, allows for a nuanced representation of uncertainties in climate-economic interactions, critical for understanding the long-term economic impacts of climate change and informing policy decisions [52]. Additionally, multi-component linear regression models (MC-LR) enhance the estimation of long-term equilibrium climate sensitivity (ECS), providing robust predictions of economic impacts [53].

Theoretical perspectives rooted in statistical modeling refine our understanding of the relationship between CO2 emissions and temperature changes [54]. Pulse response functions modeling atmospheric CO2 levels underscore the carbon cycle's sensitivity to fossil fuel emissions, shedding light on potential economic repercussions [55].

Moreover, integrating solar climate theories, which consider solar activity as a climate change driver, offers additional insights into climate impacts and their economic implications [56]. This is complemented by models like GEOCARB and GTP, which estimate safe operating spaces for greenhouse gas emissions, ensuring economic activities remain within sustainable limits [57].

The advanced modeling techniques and frameworks discussed provide critical insights into the multifaceted economic impacts of climate change, emphasizing the interplay between climate sensitivity, damage functions, and the financial sector's role in innovation diffusion. As illustrated in Figure 3, the hierarchical categorization of these advanced modeling techniques, simulation tools, and theoretical perspectives underscores the key methodologies and frameworks necessary for accurate economic impact assessments. These insights are essential for informing policy decisions and developing effective adaptation strategies, particularly in vulnerable sectors like agriculture and tourism, where economic viability is increasingly threatened by environmental changes [35, 34, 17, 16]. By leveraging these innovative approaches, researchers can enhance the precision and applicability of economic impact assessments, ultimately supporting more effective climate policy development.

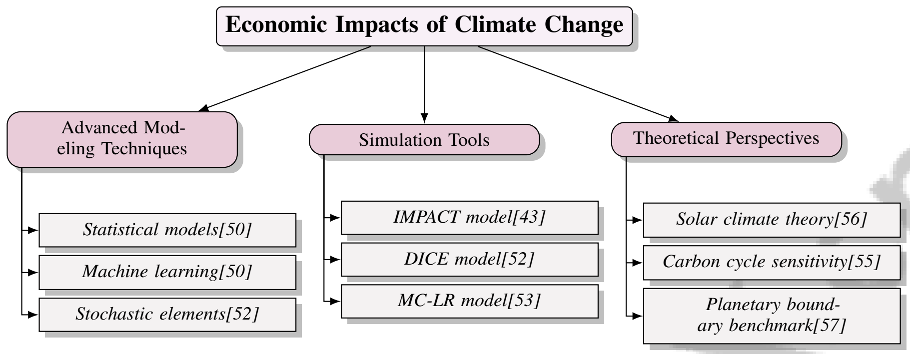


Figure 3: This figure illustrates the hierarchical categorization of advanced modeling techniques, simulation tools, and theoretical perspectives used to assess the economic impacts of climate change. The categorization highlights key methodologies and frameworks, including statistical models, machine learning, and stochastic elements, as well as simulation tools like the IMPACT and DICE models. Theoretical perspectives such as solar climate theory and carbon cycle sensitivity are also presented, emphasizing the multifaceted approach needed for accurate economic impact assessments.

4 Temperature and Rainfall Patterns

4.1 Observed Changes in Temperature and Rainfall Patterns

Global and regional shifts in temperature and precipitation patterns are evident, driven by climate change. Historical analyses linking CO2 emissions to temperature changes reveal the role of atmospheric dynamics and relative humidity in shaping global warming [54, 58]. In Western Europe, seasonal and geographical temperature variations are influenced by atmospheric and oceanic circulation [31]. The HYRAS dataset from the German Weather Service (1961-2020) highlights regional impacts on temperature, precipitation, and evaporation trends in Germany [5].

Precipitation shifts are notable, especially in arid areas where daily extremes and annual totals have risen over the past six decades [59]. Long-term rainfall data from Germany and The Netherlands corroborate these trends. Arctic sea ice variability affects regional weather, influencing temperature and precipitation dynamics, while the Walker circulation's response to warming underscores global climate interconnections [31]. In France, RCP8.5 scenario assessments of temperature data emphasize the need for robust climate models and adaptive strategies for effective climate change management [41].

4.2 Implications for Ecosystems and Agriculture

Climate-induced changes in temperature and rainfall significantly affect ecosystems and agriculture, necessitating adaptive strategies. Climate change alters pest dynamics, requiring improved management strategies to protect agricultural productivity [24]. Irregular precipitation poses risks to water resources, disrupting ecosystems and agriculture, particularly in regions like Turkey [60]. This unpredictability can lead to water scarcity, impacting irrigation and crop yields, thus emphasizing climate-smart agriculture for resilience [61].

The correlation between aerosol concentration and precipitation intensity complicates rainfall pattern understanding, with evidence suggesting aerosols may intensify precipitation events [62]. Careful data processing is crucial, especially in dry regions where statistical definitions affect rainfall trend interpretations [59]. Addressing the multifaceted challenges posed by climate change in ecosystems and agriculture requires integrating advanced research with innovative practices, fostering resilience and ensuring food security through international collaboration [63, 17, 42, 64].

4.3 Human Societal Impacts

Climate change-induced temperature and rainfall changes significantly impact human societies, affecting daily life, infrastructure, and public health. Extreme weather events, such as heatwaves and heavy precipitation, challenge urban and rural communities, necessitating robust infrastructure and emergency response systems [65]. Urban heat islands exacerbate rising temperatures, increasing energy demands and health risks for vulnerable populations [66, 44]. Adaptive strategies, including comprehensive heat action plans and enhanced green spaces, are essential.

Rural communities, especially those dependent on agriculture, face challenges from changing precipitation patterns, threatening agricultural productivity and food security. Projections indicate potential declines in rice production in Vietnam and Thailand by 2026 [63, 67, 42]. Rainfall variability can cause droughts and floods, necessitating climate-resilient agricultural practices and potentially exacerbating socio-economic inequalities.

Climate-induced temperature and rainfall changes also impact public health by altering vector-borne disease distribution. Rising temperatures and altered precipitation expand habitats for disease-carrying vectors, increasing outbreak risks. In metropolitan France, the invasive Aedes albopictus mosquito could significantly impact health by 2040 due to climate change-induced epidemics [24, 26, 25, 41]. Comprehensive adaptation strategies addressing water management, ecosystem preservation, and resilience-building are crucial to mitigate economic losses and safeguard human well-being [25, 61, 68, 30, 17].

4.4 Predictive Models and Future Scenarios

Benchmark	Size	Domain	Task Format	Metric
ET_WS[69]	8,000	Hydrology	Evapotranspiration Estimation	R
CCFSS[63]	1,000,000	Agricultural Productivity	Prediction OF Cropland Status	Balanced Accuracy, ROC-AUC
CCAF[67]	53,000	Agricultural Economics	Input-Output Analysis	Total Factor Productivity, Agricultural Yields
ERMM[70]	814	Emissions Reporting	Performance Evaluation	KPI, IND
STI-CA[14]	430,000	Climate Action	Classification	Classification Accuracy, Topic Coherence

Table 1: This table provides a comprehensive overview of representative benchmarks used in climate-related research, detailing their size, domain, task format, and evaluation metrics. These benchmarks span diverse areas such as hydrology, agricultural productivity, agricultural economics, emissions reporting, and climate action, offering insights into various methodological approaches and performance assessments.

Predictive models and future scenarios are crucial for understanding climate change's impacts on temperature and rainfall. Advances in modeling techniques, such as integrating structural time series decompositions with spatio-temporal models, enhance climate projection accuracy [71]. This allows for a nuanced examination of climate variable interactions over time and space. Table 1 presents a detailed summary of key benchmarks employed in predictive models and future scenario analyses within climate research.

CO2 accumulation findings suggest a faster climate change progression than previously anticipated, highlighting the need for dynamic models [72]. User-friendly tools like AIRCC-Clim facilitate climate projections with low computational demands, aiding policymakers and researchers [40]. Integrating predictive models into climate research enhances future scenario understanding and supports effective policy responses.

By identifying potential climate pattern shifts and effects, societies can enhance preparedness for climate change challenges. This strategic foresight fosters targeted adaptation measures, promoting resilience and sustainability across sectors, including agriculture, water resources, and biodiversity management, ensuring ecosystem service integrity vital for human well-being [22, 30].

5 Environmental Policy and Sustainable Development

5.1 International Agreements and Collaborative Efforts

International agreements and collaborative efforts are essential for addressing climate change, providing a framework for global cooperation in mitigation and sustainable development. These agreements require interdisciplinary approaches to tackle sector-specific challenges, such as the thermodynamic disequilibrium in the hydrological cycle, which impacts climate resilience and adaptation [5]. The success of these agreements is measured by their ability to foster international collaboration, which enhances global welfare more effectively than competitive strategies that could worsen climate impacts. However, the integration of climate research into policy-making is limited, with only 1.2% of studies cited in policy documents, highlighting the need to bridge the gap between scientific research and policy [4]. This underscores the necessity of increasing the visibility and application of climate research in policy-making to strengthen international cooperation [14].

Countries like the UK, USA, Germany, and Canada are leading contributors to climate research, highlighting the importance of leveraging scientific advancements for global climate policy [1]. Polycentric systems, involving multiple governance levels, have been effective in reducing emissions through localized initiatives that complement international treaties, demonstrating that empowering local efforts can significantly enhance emissions reductions. Government regulations and carbon pricing play a crucial role in shaping effective policies and investment strategies, especially as investors assess transition risks associated with the shift to a low-carbon economy. Tools like Single Event Transition Risk (SETR) provide insights into financial exposure related to low-carbon transitions, aiding stakeholders in aligning with climate adaptation goals and economic resilience [11, 73, 28]. Standardized emission reporting is vital for transparency and accountability in international agreements, ensuring accurate tracking of emission reductions to meet global targets.

5.2 National Policies and Local Initiatives

National policies and local initiatives are crucial for combating climate change by promoting sustainability and reducing emissions through tailored strategies. Integrating economic and environmental policies is necessary to achieve climate goals, with global cooperation amplifying local actions' effectiveness [74]. Urban CO2 emissions scale with economic development, with a transition point around $10,000GDPpercapita, indicatingthateconomicgrowthinfluencesemissionpatternsandnecessitatescontext-specificpolicyinterventions$[46].

In agriculture, policies focus on sustainability and emission reduction, particularly in corn farming, which is essential for resilience to climate change and minimizing agriculture's carbon footprint [75]. The economic impacts of climate change on agriculture require productive adaptations to support vulnerable farming communities and ensure food security [67]. Local efforts also emphasize energy efficiency in residential buildings, with methods quantifying heating and cooling loads to enable targeted interventions that reduce energy consumption and emissions [76]. These initiatives are vital for sustainable urban development and community resilience.

Integrating national policies and local initiatives into a cohesive framework is facilitated by clear communication and collaboration among diverse disciplines. Recent surveys propose terminology to enhance collaboration, ensuring that varied perspectives are incorporated into policy-making [34]. Aligning national and local efforts with global goals can effectively contribute to emission reductions and promote sustainable development.

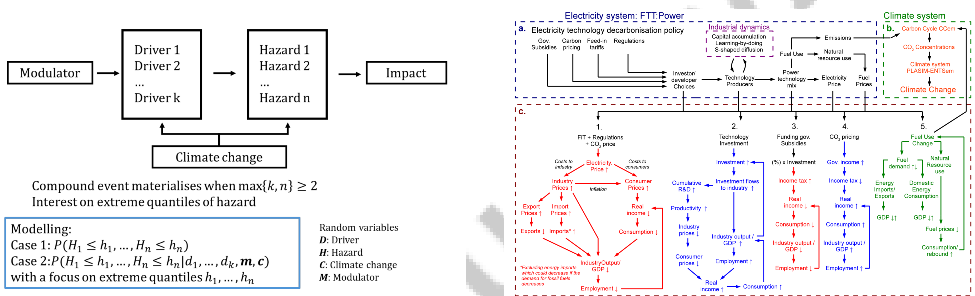
5.3 Interdisciplinary Approaches and Policy Frameworks

Interdisciplinary approaches and policy frameworks are essential for tackling climate change's complex challenges by integrating diverse scientific insights into comprehensive policy-making. Systems theory provides a holistic perspective on environmental policy-making, emphasizing system interconnectedness. Thermodynamic principles applied to model the global economy and emissions offer a robust framework for understanding the dynamics between economic activity and climate change [4].

Innovative methodologies like climate network analysis, exploring connectivity between the Amazon and the global climate system, demonstrate interdisciplinary approaches' potential to enhance climate dynamics understanding. This aids in identifying critical interactions within the climate system, informing policy decisions to preserve ecological stability and mitigate climate impacts [3]. Techno-economic analyses of energy resources and climate change interconnections lead to policy recommendations addressing energy security and environmental sustainability challenges. Policymakers can devise strategies promoting low-carbon energy systems while ensuring economic resilience [9]. The insurance industry offers a market-driven solution to climate change costs, reflecting an interdisciplinary approach that manages risk and incentivizes sustainable practices [11].

Advancements in emissions reporting, using AI-driven clustering techniques, enhance transparency and accountability, supporting robust policy frameworks aligned with global climate goals. Natural language processing methodologies create comprehensive knowledge platforms for climate policy, exemplifying interdisciplinary tools' potential to facilitate policy development and stakeholder engagement [13].

Incorporating stochastic interest rates and non-linear funding costs into climate models can improve intergenerational equity by addressing discount rate uncertainties and alleviating future generations' financial burden. Traditional models, like DICE, often exacerbate intergenerational inequality by inadequately distributing mitigation costs. By integrating stochastic elements and funding mechanisms, resources and responsibilities can be allocated more equitably, supporting a fair transition to a net-zero emissions economy while keeping mitigation costs below 3% of global GDP [52, 11, 28, 77]. This approach ensures policy frameworks consider long-term climate action implications, fostering intergenerational equity and sustainable development.



(a) Climate Change and Compound Events: A Modelling Framework[78]

(b) Electricity system: FTT:Power[16]

Figure 4: Examples of Interdisciplinary Approaches and Policy Frameworks

As illustrated in Figure 4, the example "Environmental Policy and Sustainable Development: Interdisciplinary Approaches and Policy Frameworks" explores the intricate relationships between climate change, energy systems, and policy development. The first flowchart, "Climate Change and Compound Events: A Modelling Framework," systematically portrays how climate change influences compound events, emphasizing the role of modulators in these interactions. This model highlights the complexity of climate-related phenomena and the need for comprehensive frameworks to understand their multifaceted impacts. The second flowchart, "Electricity System: FTT:Power," illustrates the dynamic interplay between electricity technology decarbonization policies, government subsidies, and carbon pricing, underscoring the essential role of policy frameworks in steering the transition towards sustainable energy systems. Together, these examples reinforce the significance of interdisciplinary approaches in formulating effective environmental policies that address the challenges of sustainable development amidst climate change [78, 16].

6 Carbon Emissions and Mitigation Strategies

6.1 Sources and Impacts of Carbon Emissions

Carbon emissions from human activities, notably fossil fuel combustion for energy and transport, are pivotal in climate change discussions, significantly contributing to global warming [55]. Complex feedback mechanisms, such as those involving temperature, carbon levels, and ice dynamics, further complicate climate systems [38]. Machine learning techniques have been pivotal in reconstructing historical CO2 emissions, revealing evolving patterns and underscoring the importance of technological integration in emission assessments [79].

Agricultural activities, including deforestation and livestock farming, are also major emission sources, with welfare analyses indicating the need for comprehensive evaluations of agricultural productivity losses due to climate change [29]. Additionally, tourism is a significant emitter, necessitating low-carbon strategies [7]. Urban areas, with challenges like heat islands and data variability, complicate accurate assessments of temperature impacts [66]. The weakening Walker circulation further influences carbon dynamics, highlighting global climate system interconnections [31]. Emission spatial distribution reveals socio-economic disparities, emphasizing equitable energy access [2].

Beyond environmental changes, carbon emissions impact socio-economic systems and public health, as illustrated by intensified heatwaves in India driven by Rossby waves and regional forcing [80]. Addressing these impacts requires a multifaceted approach integrating technology, data analysis, and interdisciplinary research to enable effective mitigation of carbon emissions' adverse effects on global systems.

6.2 Technological Innovations in Emission Reduction

Technological innovations are vital for enhancing carbon emission reduction efforts, offering advanced tools and methodologies to bolster climate resilience and decarbonization goals. The AI-driven Integrative Emissions Monitoring Management Framework (AI-IEMM) exemplifies this by employing artificial intelligence to manage emissions linked to nature-based solutions, enhancing precision and efficiency [81].

In climate modeling, integrating historical data with future predictions has improved General Circulation Models (GCMs), reducing uncertainties and informing effective strategies [82]. Machine learning enhances these models' accuracy, making them operationally feasible [83]. Simplified global models exploring state-dependent climate sensitivity offer insights into predicting emissions and impacts [39].

The energy sector's investments in photovoltaic capacity and storage solutions are crucial for meeting future demands amid extreme weather, ensuring power system resilience, as shown in Italy [18]. Climate-contingent finance aligns investment returns with climate outcomes, facilitating proactive adaptation funding [11].

Innovations in modeling complex systems enhance understanding of emissions and impacts. Using peak fossil fuel emissions and first-difference CO2 relationships, researchers improve climate predictions [54]. Integrating climate uncertainty quantification in energy models emphasizes collaboration between modeling communities to ensure comprehensive strategies [84].

These innovations underscore advanced methodologies and collaborative efforts' importance in reducing emissions. Leveraging advancements in NLP and data analysis, policymakers can devise strategies to address climate change's multifaceted impacts, promoting sustainable development across sectors like agriculture, health, and infrastructure. Strategies should incorporate diverse perspectives, fostering a holistic approach to climate policy aligned with global commitments like the Paris Agreement [22, 4, 68, 21, 17].

6.3 Economic and Policy-Based Mitigation Strategies

Economic and policy-based strategies are essential for effective carbon emission mitigation, necessitating a comprehensive approach that integrates technology, regulatory frameworks, and collaboration among governments, businesses, and communities. The IMPACT model enables cities to forecast emission pathways based on decision-making and policy influences, providing a flexible framework for local adaptation [43].

Aligning urban cooling strategies with behavioral adaptations, like increasing setpoint temperatures, can significantly reduce energy demand, highlighting regulatory interventions' role in managing urban energy consumption [44]. This approach shows how minor behavioral changes, supported by policies, yield substantial energy savings and emission reductions.

Technological innovations, such as the AIRCC-Clim tool, create probabilistic climate projections with reduced computational demands, enhancing climate data incorporation into economic strategies

[40]. These tools help policymakers devise data-driven, adaptable strategies for changing climate scenarios.

Financial mechanisms are crucial in mitigation strategies; incorporating stochastic interest rates and funding mechanisms improves intergenerational equity, ensuring equitable climate action cost distribution [52]. Findings indicate that financial frictions increase optimal abatement and carbon taxes, highlighting the need for economic policies addressing these frictions to enhance mitigation [85].

The risk of tipping points, like AMOC destabilization, emphasizes robust emission reduction strategies' urgency to avert catastrophic outcomes [86]. Collaborative efforts to manage planetary boundaries, incorporating interaction terms between environmental limits, provide a sustainable resource management framework [87].

Integrating multiple datasets to analyze climate change and natural disasters enhances understanding through statistical models, informing policy decisions [47]. Promoting innovation in production and advancing green technologies are essential for emissions reduction [10]. A multidisciplinary approach enhances understanding of green hydrogen potentials in Sub-Saharan Africa, providing a robust decision-making framework [3].

6.4 Sector-Specific Mitigation Approaches

Sector-specific mitigation strategies are crucial for addressing carbon emissions' diverse challenges. In urban contexts, sustainability challenges necessitate integrated assessment frameworks considering urban dynamics like energy consumption, transportation, and waste management [88]. These frameworks inform comprehensive urban sustainability strategies.

In agriculture, high-resolution modeling of land-atmosphere interactions is vital for understanding soil moisture's impact on extreme weather, enabling adaptive water management strategies critical for maintaining productivity and mitigating climate impacts [12]. Strategies should optimize irrigation practices and enhance soil conservation to ensure resilience against climate variability.

The energy sector requires innovative approaches to integrate renewables into infrastructures. Hybrid models blending Monte Carlo methods with atmospheric flow models improve urban climate simulations, enhancing energy demand forecasts and facilitating low-carbon system transitions [13]. These models provide insights into renewable integration effects on urban networks, informing policy decisions.

Sector-specific strategies must address transportation, where reducing vehicle emissions and promoting public transit can significantly lower carbon footprints. Policies incentivizing electric vehicle adoption and enhancing public transit systems lead to notable reductions, as evidenced by integrated modeling frameworks accounting for technology adoption, land-use zoning, and climate scenarios. Targeted strategies are vital for cities facing urbanization and sustainable growth needs, preventing carbon lock-in and optimizing emissions reporting through performance indicators and AI [43, 89, 70, 20].

7 Conclusion

7.1 Challenges and Future Directions

Tackling the intricate challenges posed by climate change demands a robust interdisciplinary approach that seamlessly integrates scientific inquiry, technological innovation, and comprehensive policy frameworks. A significant hurdle is the refinement of climate models to enhance their precision, particularly in representing cloud dynamics, humidity fluctuations, and natural variability, which are pivotal in shaping climate patterns. Advancements in these areas are crucial for developing a deeper understanding of climate impacts and refining future climate projections.

Research efforts must focus on advancing models that incorporate the interplay between temperature and hydromechanical processes, offering a more holistic perspective on slope stability. Furthermore, strengthening climate-contingent financial mechanisms is imperative, as enhanced predictive accuracy can significantly improve decision-making processes across diverse sectors.

Another pressing challenge involves the creation of more sophisticated Integrated Assessment Models (IAMs) that comprehensively address transitional mitigation costs and elucidate the economic ramifications of climate policies, especially those related to induced economic disparities. Current limitations in global climate models, particularly their coarse resolution, often fail to accurately capture regional dynamics in complex terrains. Therefore, future research should aim to refine these models by integrating real-time data and examining additional factors such as socio-economic transformations and technological progress.

In urban environments, lingering uncertainties about the long-term effects of climate change and the efficacy of adaptation strategies persist. Future endeavors should focus on refining urban climate models to better comprehend these impacts and devise effective adaptation measures. Additionally, exploring the applicability of benchmarking approaches to other Sustainable Development Goals (SDGs) and diverse geographical contexts could enhance the synergy between climate research and policy-making.

Addressing climate change challenges requires a holistic strategy that leverages technological advancements and scientific insights. By pursuing these research directions, the scientific community can develop more effective strategies to combat climate change and promote sustainable development.

References

[1] Robin Haunschild, Lutz Bornmann, and Werner Marx. Climate change research in view of bibliometrics, 2016.

[2] Duo Zhang, Yuren Pang, and Yu Qin. Dynamic grouping for climate change negotiation: Facilitating cooperation and balancing interests through effective strategies, 2023.

[3] Shitab Ishmam, Heidi Heinrichs, Christoph Winkler, Bagher Bayat, Amin Lahnaoui, Solomon Agbo, Edgar Ubaldo Pena Sanchez, David Franzmann, Nathan Ojieabu, Celine Koerner, Youpele Micheal, Bamidele Oloruntoba, Carsten Montzka, Harry Vereecken, Harrie-Jan Hendricks-Franssen, Jeerawan Brendt, Simon Brauner, Wilhelm Kuckshinrichs, Sandra Venghaus, Daouda Kone, Bruno Korgo, Kehinde Ogunjobi, Vasco Chiteculo, Jane Olwoch, Zachary Getenga, Jochen Linßen, and Detlef Stolten. Mapping local green hydrogen cost-potentials by a multidisciplinary approach, 2024.

[4] Lutz Bornmann, Robin Haunschild, and Werner Marx. Policy documents as sources for measuring societal impact: How often is climate change research mentioned in policy-related documents?, 2016.

[5] Axel Kleidon. Droughts in germany – why global climate change amplifies hydrological extremes, 2024.

[6] Leon Schumm, Hazem Abdel-Khalek, Tom Brown, Falko Ueckerdt, Michael Sterner, Davide Fioriti, and Max Parzen. The impact of temporal hydrogen regulation on hydrogen exporters and their domestic energy transition, 2024.

[7] Xiaopeng Si and Zi Tang. Assessment of low-carbon tourism development from multi-aspect analysis: A case study of the yellow river basin, china, 2024.

[8] Doris Folini, Felix Kübler, Aleksandra Malova, and Simon Scheidegger. The climate in climate economics, 2022.

[9] Marco Loche and Gianvito Scaringi. Temperature continuously controls the stability of clay slopes, 2022.

[10] María José Presno, Manuel Landajo, and Paula Fernández González. Ghg emissions in the eu-28. a multilevel club convergence study of the emission trading system and effort sharing decision mechanisms, 2024.

[11] John Nay. Climate-contingent finance, 2022.

[12] Matilde García-Valdecasas Ojeda, Patricio Yeste, Sonia Raquel Gámiz-Fortis, Yolanda Castro-Díez, and María Jesús Esteban-Parra. Future changes in land and atmospheric variables: An analysis of their couplings in the iberian peninsula, 2024.

[13] Najda Villefranque, Frédéric Hourdin, Louis d'Alençon, Stéphane Blanco, Olivier Boucher, Cyril Caliot, Christophe Coustet, Jérémi Dauchet, Mouna El Hafi, Olivier Farges, Vincent Forest, Richard Fournier, Valéry Masson, Benjamin Piaud, and Robert Schoetter. The "teapot in a city": a paradigm shift in urban climate modeling, 2022.

[14] Nicandro Bovenzi, Nicolau Duran-Silva, Francesco Alessandro Massucci, Francesco Multari, Cèsar Parra-Rojas, and Josep Pujol-Llatse. Mapping sti ecosystems via open data: overcoming the limitations of conflicting taxonomies. a case study for climate change research in denmark, 2022.

[15] Richard S. J. Tol. A meta-analysis of the total economic impact of climate change, 2022.

[16] J. F. Mercure, H. Pollitt, U. Chewpreecha, P. Salas, A. Foley, P. B. Holden, and N. R. Edwards. Complexity, economic science and possible economic benefits of climate change mitigation policy, 2015.

[17] Kashif Abbass, Muhammad Zeeshan Qasim, Huaming Song, Muntasir Murshed, Haider Mahmood, and Ijaz Younis. A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environmental science and pollution research*, 29(28):42539–42559, 2022.

[18] Alice Di Bella and Francesco Pietro Colelli. Ensuring resilience to extreme weather events increases the ambition of mitigation scenarios on solar power and storage uptake: a study on the italian power system, 2024.

[19] James Hansen, Makiko Sato, Pushker Kharecha, Karina von Schuckmann, David J Beerling, Junji Cao, Shaun Marcott, Valerie Masson-Delmotte, Michael J Prather, Eelco J Rohling, Jeremy Shakun, and Pete Smith. Young people's burden: Requirement of negative co2 emissions, 2017.

[20] Romit Maulik, Junghwa Choi, Wesley Wehde, and Prasanna Balaprakash. Determining feature importance for actionable climate change mitigation policies, 2020.

[21] Pradip Swarnakar and Ashutosh Modi. Nlp for climate policy: Creating a knowledge platform for holistic and effective climate action, 2021.

[22] Alexandra Luccioni, Emily Baylor, and Nicolas Duchene. Analyzing sustainability reports using natural language processing, 2020.

[23] Gretta T Pecl, Miguel B Araújo, Johann D Bell, Julia Blanchard, Timothy C Bonebrake, I-Ching Chen, Timothy D Clark, Robert K Colwell, Finn Danielsen, Birgitta Evengård, et al. Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science*, 355(6332):eaai9214, 2017.

[24] Sandra Skendžić, Monika Zovko, Ivana Pajač Živković, Vinko Lešić, and Darija Lemić. The impact of climate change on agricultural insect pests. *Insects*, 12(5):440, 2021.

[25] Gurdeep Singh Malhi, Manpreet Kaur, and Prashant Kaushik. Impact of climate change on agriculture and its mitigation strategies: A review. *Sustainability*, 13(3):1318, 2021.

[26] David Dunn and James P. Crutchfield. Entomogenic climate change, 2008.

[27] Qianqian Li, Giuliano Punzo, Craig Robson, Hadi Arbabi, and Martin Mayfield. A novel approach to climate resilience of infrastructure networks, 2022.

[28] Wasim Ahmad, Mohammad Arshad Rahman, Suruchi Shrimali, and Preeti Roy. Tuning into climate risks: Extracting innovation from television news for clean energy firms, 2024.

[29] Alkis Blanz. Climate-related agricultural productivity losses through a poverty lens, 2023.

[30] Camille Parmesan, Mike D Morecroft, and Yongyut Trisurat. *Climate change 2022: Impacts, adaptation and vulnerability*. PhD thesis, GIEC, 2022.

[31] Timothy M. Merlis and Tapio Schneider. Changes in zonal surface temperature gradients and walker circulations in a wide range of climates, 2011.

[32] Max Falkenberg, Alessandro Galeazzi, Maddalena Torricelli, Niccolo Di Marco, Francesca Larosa, Madalina Sas, Amin Mekacher, Warren Pearce, Fabiana Zollo, Walter Quattrociocchi, and Andrea Baronchelli. Growing polarisation around climate change on social media, 2022.

[33] Bram Renting, Phillip Wozny, Robert Loftin, Claudia Wieners, and Erman Acar. Ai4gcc - team: Below sea level: Critiques and improvements, 2023.

[34] Robert E. Kopp, Rachael Shwom, Gernot Wagner, and Jiacan Yuan. Tipping elements and climate-economic shocks: Pathways toward integrated assessment, 2016.

[35] Jenny Bjordal, Trude Storelvmo, and Anthony A. Smith Jr au2. Quantifying uncertainty about global and regional economic impacts of climate change, 2021.

[36] Adam Giammarese, Jacob Brown, and Nishant Malik. Reconfiguration of amazon's connectivity in the climate system, 2023.

[37] Timothy J. Garrett. No way out? the double-bind in seeking global prosperity alongside mitigated climate change, 2012.

[38] Lucas Benney and Anca Radulescu. An energy balance model of carbon's effect on climate change, 2015.

[39] James Hansen, Makiko Sato, Gary Russell, and Pushker Kharecha. Climate sensitivity, sea level, and atmospheric co2, 2013.

[40] Francisco Estrada, Oscar Calderón-Bustamante, Wouter Botzen, Julián A. Velasco, and Richard S. J. Tol. Aircc-clim: a user-friendly tool for generating regional probabilistic climate change scenarios and risk measures, 2021.

[41] Yannick Drif, Benjamin Roche, and Pierre Valade. Conséquences du changement climatique pour les maladies à transmission vectorielle et impact en assurance de personnes, 2020.

[42] Ariel Ortiz-Bobea. Climate, agriculture and food, 2021.

[43] Juliana Felkner, Zoltan Nagy, Ariane L. Beck, D. Cale Reeves, Steven Richter, Vivek Shastry, Eli Ramthun, Edward Mbata, Stephen Zigmund, Benjamin Marshall, Linnea Marks, Vianey Rueda, Jasmine Triplett, Sarah Domedead, Jose R Vazquez-Canteli, and Varun Rai. Impact: Integrated bottom-up greenhouse gas emission pathways for cities, 2024.

[44] Haiwei Li, Yongling Zhao, Ronita Bardhan, Pak-Wai Chan, Dominique Derome, Zhiwen Luo, Diana Urge-Vorsatz, and Jan Carmeliet. Aligning three-decade surge in urban cooling with global warming, 2023.

[45] Geoff Boeing, Clemens Pilgram, and Yougeng Lu. Urban street network design and transport-related greenhouse gas emissions around the world, 2024.

[46] Diego Rybski, Dominik E. Reusser, Anna-Lena Winz, Christina Fichtner, Till Sterzel, and Jürgen P. Kropp. Cities as nuclei of sustainability?, 2015.

[47] Sukeerthi Mandyam, Shanmuga Priya, Shalini Suresh, and Kavitha Srinivasan. A correlation analysis and visualization of climate change using post-disaster heterogeneous datasets, 2022.

[48] Jose M. Tarraga, Maria Piles, and Gustau Camps-Valls. Learning drivers of climate-induced human migrations with gaussian processes, 2020.

[49] MohammadReza Askari and Navid Parsa. A techno-economic analysis of the interconnectedness between energy resources, climate change, and sustainable development, 2024.

[50] Hamed Khosravi, Ahmed Shoyeb Raihan, Farzana Islam, Ashish Nimbarte, and Imtiaz Ahmed. A comprehensive approach to carbon dioxide emission analysis in high human development index countries using statistical and machine learning techniques, 2024.

[51] Luís Costa, Diego Rybski, and Jürgen P. Kropp. A human development framework for co2 reductions, 2012.

[52] Christian Fries and Lennart Quante. Intergenerational equity in models of climate change mitigation: Stochastic interest rates introduce adverse effects, but (non-linear) funding costs can improve intergenerational equity, 2023.

[53] Robbin Bastiaansen, Henk A. Dijkstra, and Anna S. von der Heydt. Multivariate estimations of equilibrium climate sensitivity from short transient warming simulations, 2020.

[54] L. Mark W. Leggett and David. A. Ball. Forecasts of the trend in global-mean temperature to 2100 arising from the scenarios of first-difference co2 and peak fossil fuel, 2020.

[55] P. A. Kharecha and J. E. Hansen. Implications of "peak oil" for atmospheric co2 and climate, 2008.

[56] Igor Khmelinskii and Peter Stallinga. Climate change policies for the xxist century: Mechanisms, predictions and recommendations, 2014.

[57] Steffen Petersen, Morten W. Ryberg, and Morten Birkved. The safe operating space for greenhouse gas emissions, 2022.

[58] Jyrki Kauppinen and Pekka Malmi. No experimental evidence for the significant anthropogenic climate change, 2019.

[59] Sebastian Sippel, Jakob Zscheischler, Martin Heimann, Holger Lange, Miguel D. Mahecha, Geert Jan van Oldenborgh, Friederike E. L. Otto, and Markus Reichstein. Have precipitation extremes and annual totals been increasing in the world's dry regions over the last 60 years?, 2016.

[60] Mesut Demircan, Hüdaverdi Gürkan, Osman Eskioğlu, Hüseyin Arabacı, and Mustafa Coşkun. Climate change projections for turkey: three models and two scenarios. *Turkish Journal of Water Science and Management*, 1(1):22–43, 2017.

[61] Environmental sustainability (20.

[62] Chongxing Fan, Maiqi Ding, Peipei Wu, and Yaqi Fan. The relationship between precipitation and aerosol: Evidence from satellite observation, 2019.

[63] Tanushkina Daria, Shevchenko Valeriy, Lukashevich Aleksander, Bulkin Aleksandr, Grinis Roland, Kovalev Kirill, Narozhnaia Veronika, Sotiriadi Nazar, Krenke Alexander, and Maximov Yury. Climate change and future food security: Predicting the extent of cropland gain or degradation, 2023.

[64] Francesca Larosa, Jaroslav Mysiak, Marco Molinari, Panagiotis Varelas, Haluk Akay, Will McDowall, Catalina Spadaru, Francesco Fuso-Nerini, and Ricardo Vinuesa. Closing the gap between research and projects in climate change innovation in europe, 2023.

[65] Ziwei Li and Paul O'Gorman. Response of vertical velocities in extratropical precipitation extremes to climate change, 2020.

[66] Babak Jalalzadeh Fard, Udit Bhatia, and Auroop R. Ganguly. Mega regional heat patterns in us urban corridors, 2020.

[67] Fernando M. Aragón, Francisco Oteiza, and Juan Pablo Rud. Climate change and agriculture: Subsistence farmers' response to extreme heat, 2019.

[68] Samer Fawzy, Ahmed I Osman, John Doran, and David W Rooney. Strategies for mitigation of climate change: a review. *Environmental Chemistry Letters*, 18:2069–2094, 2020.

[69] Haiyang Shi. Global pattern and mechanism of terrestrial evapotranspiration change indicated by weather stations, 2023.

[70] Victor de A. Xavier, Felipe M. G. França, and Priscila M. V. Lima. Emissions reporting maturity model: supporting cities to leverage emissions-related processes through performance indicators and artificial intelligence, 2023.

[71] Marcio Poletti Laurini. A continuous spatio-temporal approach to estimate climate change, 2017.

[72] Jessie Lydia Henshaw. The systemic growth constants of climate change: From its origin in 1780 to its major post-wwii acceleration, 2019.

[73] Suryadeepto Nag, Siddhartha P. Chakrabarty, and Sankarshan Basu. Single event transition risk: A measure for long term carbon exposure, 2022.

[74] Mostapha Kalami Heris and Shahryar Rahnamayan. Multi-objective optimal control of dynamic integrated model of climate and economy: Evolution in action, 2020.

[75] Antoine Kornprobst and Matt Davison. Influence of climate change on the corn yield in ontario and its impact on corn farms income at the 2068 horizon, 2020.

[76] Raj S. Srivastava, A. Aravinda De Chinnu, and Aakash C. Rai. A multi-model and multi-scenario assessment of the impact of climate change on the heating and cooling load components of an archetypical residential room in major indian cities, 2023.

[77] Christian P. Fries and Lennart Quante. Intergenerational equitable climate change mitigation: Negative effects of stochastic interest rates; positive effects of financing, 2024.

[78] Kwok P Chun, Thanti Octavianti, Georgia Papacharalampous, Hristos Tyralis, Samuel J. Sutanto, Pavel Terskii, Paola Mazzoglio, Dario Treppiedi, Juan Rivera, Nilay Dogulu, Adeyemi Olusola, Bastien Dieppois, Moctar Dembélé, Simon Moulds, Cheng Li, Luis Alejandro Morales-Marin, Neil Macdonald, Toundji Olivier Amoussou, Roland Yonaba, Salomon Obahoundje, Nicolas Massei, David M. Hannah, Sivarama Krishna Reddy Chidepudi, and Byman Hamududu. Unravelling compound risks of hydrological extremes in a changing climate: Typology, methods and futures, 2024.

[79] Tao Li, Lixing Wang, Zihan Qiu, Philippe Ciais, Taochun Sun, Matthew W. Jones, Robbie M. Andrew, Glen P. Peters, Piyu ke, Xiaoting Huang, Robert B. Jackson, and Zhu Liu. Reconstructing global daily co2 emissions via machine learning, 2024.

[80] Lekshmi S, Rajib Chattopadhyay, and D. S. Pai. Dynamics of heatwave intensification over the indian region, 2024.

[81] Olamide Oladeji and Seyed Shahabeddin Mousavi. Towards ai-driven integrative emissions monitoring management for nature-based climate solutions, 2023.

[82] Debashis Chatterjee and Sourabh Bhattacharya. How ominous is the future global warming premonition?, 2020.

[83] Peter A. G. Watson. Applying machine learning to improve simulations of a chaotic dynamical system using empirical error correction, 2019.

[84] Michael T. Craig, Jan Wohland, Laurens P. Stoop, Alexander Kies, Bryn Pickering, Hannah C. Bloomfield, Jethro Browell, Matteo De Felice, Chris J. Dent, Adrien Deroubaix, Felix Frischmuth, Paula L. M. Gonzalez, Aleksander Grochowicz, Katharina Gruber, Philipp Härtel, Martin Kittel, Leander Kotzur, Inga Labuhn, Julie K. Lundquist, Noah Pflugradt, Karin van der Wiel, Marianne Zeyringer, and David J. Brayshaw. Overcoming the disconnect between energy system and climate modeling, 2023.

[85] Felix Kübler. Climate uncertainty, financial frictions and constrained efficient carbon taxation, 2022.

[86] René M. van Westen, Elian Y. P. Vanderborght, Michael Kliphuis, and Henk A. Dijkstra. Substantial risk of 21st century amoc tipping even under moderate climate change, 2024.

[87] M. Barbosa, O. Bertolami, and F. Francisco. Towards a physically motivated planetary accounting framework, 2019.

[88] Dasaraden Mauree, Emanuele Naboni, Silvia Coccolo, A. T. D. Perera, Vahid Nik, and Jean-Louis Scartezzini. A review of assessment methods for the urban environment and its energy sustainability to guarantee climate adaptation of future cities, 2019.

[89] Pedro V Hernandez Serrano and Amrapali Zaveri. Venturing the definition of green energy transition: A systematic literature review, 2020.