

IMPLICATIONS OF CLIMATE CHANGE AND ECOSYSTEM SERVICES DEGRADATION FOR MACROECONOMIC AND FINANCIAL STABILITY: AN OVERVIEW

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This volume collects some of the papers presented at the XXVI Annual Conference of the Central Bank of Chile, which took place in November 2023 in Santiago, Chile.¹ The theme of the conference was **Implications of Climate Change and Ecosystem Services Degradation for Macroeconomic and Financial Stability**. The main objective of the conference was to bring together a select group of economists in the fields of environmental economics and macroeconomics dedicated to exploring the impacts of natural resource degradation on macroeconomic and financial stability.

In recent decades, we have observed an accelerating degradation of natural systems, with tangible and escalating consequences. Numerous countries are now experiencing more frequent and intense extreme heat events, elevated maximum temperatures, declining river flows, and an increase in large-scale fires, droughts, and other forms of climate-related disruption. The Intergovernmental Panel on Climate Change (IPCC) underscored these developments in its 2022 Sixth Assessment Report, which delivered a stark message: there remains a growing gap between the emissions trajectory required

1. The full program is available on the Central Bank's webpage.

Implications of Climate Change and Ecosystem Services Degradation for Macroeconomic and Financial Stability, edited by Maximilian Auffhammer, Elías Albagli, Sofia Bauducco, and Gonzalo García-Trujillo, Santiago, Chile. © 2025 Central Bank of Chile.

to meet the objectives of the Paris Agreement, specifically limiting global warming to 1.5°C or, at most, 2°C by the end of the century, and the emissions pathways implied by current Nationally Determined Contributions.² As the report states, “current climate pledges to 2030 would make it ‘impossible’ to limit warming to 1.5°C with ‘no or limited overshoot’—and ‘strongly increase the challenge’ for 2°C.” Parallel to this, the 2019 Global Assessment Report on Biodiversity and Ecosystem Services, released by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), presents extensive empirical evidence of a rapid and ongoing global decline in biodiversity. The report estimates that 75% of terrestrial environments and 66% of marine areas have already undergone substantial human-induced change. Together, these findings indicate that while ecological systems are issuing increasingly urgent warnings about the risks of a delayed green transition, global responses continue to follow a path characterized by insufficient urgency and late-stage intervention.

The IPCC’s emphasis on achieving “no or limited overshoot” highlights the critical importance of the emissions trajectory en route to net zero by mid-century. Even a temporary overshoot beyond the 2°C threshold entails substantial risks and costs. Such a deviation would not only increase the economic burden of transition—potentially necessitating large-scale deployment of carbon dioxide removal technologies—but also heighten the likelihood of breaching climate tipping points. This, in turn, would elevate the probability of widespread and irreversible impacts, including damage to built infrastructure, displacement in low-lying coastal regions, and degradation of ecologically sensitive zones such as polar, alpine, and coastal ecosystems.³ These consequences carry systemic implications, as the resilience of human societies is fundamentally tied to the stability and continued functioning of the diverse ecosystems upon which we rely.⁴

Beyond the direct climatic consequences, a delayed transition poses substantial systemic risks to human welfare and geopolitical stability. The disruption to the well-being of billions of people over the coming decades has the potential to catalyze complex secondary effects, including large-scale migration flows, intensified domestic political polarization, and heightened international tensions. The cumulative

2. IPCC (2023).

3. See OECD (2022).

4. See, for example, Dasgupta (2021).

societal and economic costs associated with these dynamics may far exceed the investments required to implement a timely and effective climate and environmental transition. Accordingly, it is imperative to expedite mitigation strategies while simultaneously advancing adaptation measures aimed at enhancing economic resilience throughout the transition to net-zero emissions.

It is equally essential to recognize that the policies and investments required to facilitate the net-zero transition will carry macroeconomic implications. On one side, the scale of additional capital expenditure needed may place upward pressure on the cost of capital, and certain tax instruments designed to incentivize the shift toward cleaner energy sources may introduce market distortions that could, in turn, influence growth trajectories. However, it is equally important to underscore that, as with any major structural transformation driven by large-scale investment, the transition holds the potential to generate net positive economic outcomes over the medium term, beyond its environmental gains. These benefits include downward pressure on long-term energy prices and the creation of new employment opportunities and business ventures in sectors positioned to expand within a more sustainable global economic framework.

To shed light on these challenges, this volume presents seven papers, as well as two keynote addresses, delivered by Philippe Aghion and Maximilian Auffhammer, that provide critical insights into four topics: macroeconomic impacts of climate change, macroeconomic impacts of ecosystem services degradation, climate change and biodiversity loss as a financial risk, and climate change and ecosystem services degradation from a multidisciplinary perspective.

The first three papers examine the macroeconomic consequences of climate change, underscoring that climate risks are not tangential but fundamental to contemporary macroeconomic analysis and policy design. These papers argue for the urgent integration of environmental considerations into economic decision-making frameworks.

The opening paper, authored by Cédric Crofils, Nicolás Durán, Javier Ledezma, Víctor Riquelme, and Juan M. Wlasiuk, entitled **Central Banks and Sustainability: A Comprehensive Review of Green Mandates, Speeches, and Actions**, presents a detailed review of how 125 central banks are incorporating environmental objectives into their mandates, communications, and operational activities. Prompted by the growing consensus that climate risk poses a threat to financial stability, the authors systematically assess speeches, policy statements, and institutional initiatives across

major jurisdictions. Their analysis categorizes instruments such as climate scenario modeling, stress testing, and mandatory disclosures, documenting their adoption over time.

The findings point to a gradual but clear shift: central banks are increasingly embedding sustainability within their mandates, both formally and informally, as well as within their public communications. There is also a marked uptick in central bank research output on climate-related topics, which reflects a growing institutional commitment to understanding environmental risks and exploring their macrofinancial implications. The study also identifies significant variation across countries: central banks in wealthier and larger economies show greater levels of engagement, while those in countries with high inflation or heavy dependence on natural resources tend to be less active. Notably, stronger democratic institutions and higher exposure to climate risks correlate positively with greater central bank involvement in environmental issues.

The Short-Run Macroeconomics of the Energy Transition: A Review and Directions for Research, by Adrien Bilal and James H. Stock, surveys the growing empirical literature on the near-term macroeconomic implications of energy transition policies, with a particular emphasis on policy uncertainty, geopolitical transition risks, and the inflationary pressures associated with decarbonization. Recognizing the transition to a low-carbon energy system as one of the most consequential structural shifts currently confronting the global economy, with far-reaching effects on macroeconomic stability, international relations, and policymaking, the authors aim to synthesize current empirical insights and chart a course for future research.

Their review yields two principal conclusions. First, large-scale climate policies, those that encompass a substantial share of emissions and economic activity, can exert contractionary effects on short-run real economic output. However, the magnitude and persistence of these effects hinge critically on policy design. Climate policies that deliver predictable and gradual carbon pricing, such as a well-calibrated carbon tax, tend to generate fewer adverse economic effects. In contrast, those introducing high levels of volatility and uncertainty in carbon pricing, such as certain cap-and-trade mechanisms, are more likely to disrupt macroeconomic conditions. The authors thus advocate for policy architectures that minimize volatility in both explicit and implicit carbon prices. Second, recent inflationary episodes (notably from 2021 to 2024) appear to have been partly driven by energy market

disruptions, a trend likely to continue. Even under ambitious net-zero scenarios, fossil fuel demand in advanced economies is expected to remain significant due to inelastic consumption patterns and slow supply adjustments. Given the structure of global energy markets, this persistence implies ongoing exposure to geopolitical risks and supply-side shocks. Bilal and Stock argue that, while central banks have developed tools to manage traditional energy supply disruptions, there is an urgent need to deepen our understanding of how these shocks will evolve in the context of decarbonization.

Next is the keynote lecture by Philippe Aghion, **Innovation, Growth, and Environmental Challenges: Schumpeterian Insights into Climate Change and Green Technologies**, which explores how the macroeconomic considerations of the energy transition, outlined in the preceding paper, intersect with the role of innovation in achieving sustainable growth. Drawing on a Schumpeterian framework, Aghion emphasizes that the mechanism of creative destruction, whereby new technologies and firms displace outdated incumbents, can simultaneously drive long-run economic growth and support decarbonization. He argues that sustained growth is rooted in the accumulation of innovations, spurred by the prospect of entrepreneurial rents. However, the innovation process is both dynamic and path-dependent, thus requiring a carefully constructed policy mix. While carbon pricing is necessary to internalize the environmental externalities of emissions, it is insufficient on its own. Complementary industrial policies, such as targeted R&D subsidies and direct support for clean technologies, are also required to overcome market failures specific to green innovation.

Aghion directly engages with the “degrowth” position, challenging the notion that halting or reversing economic growth is either necessary or effective in addressing environmental degradation. Instead, he advocates for a strategy of directed technological change, deliberately channeling innovation toward low-carbon solutions, as a viable and constructive response. His argument is grounded in the idea that, under the right institutional arrangements and incentive structures, economic growth and environmental sustainability are not in conflict. Rather, they can be aligned, with green innovation serving as the mechanism that reconciles ecological imperatives with continued prosperity.

The following two papers shift the focus toward the macroeconomic implications of ecosystem services degradation.

Integrating Ecosystem Modeling into Economic Models: Applications to Efficiency Analysis, Gross Ecosystem Product, and Policy Analysis, by Stephen Polasky, underscores the necessity of embedding ecological modeling within economic frameworks to more effectively manage the sustainable use of natural capital. Ecosystems deliver foundational services, such as pollination, water purification, and climate regulation, which are critical to both human welfare and economic systems. Yet, due to their public good nature and the persistence of market failures, these services are frequently undervalued, overlooked, and inadequately protected. This raises the imperative for more integrated modeling approaches that can better characterize ecological vulnerabilities and guide the design of more sustainable policy responses.

Polasky introduces a biophysical-economic modeling framework that couples ecological process models with economic valuation tools to quantify how anthropogenic pressures, such as habitat loss, pollution, and overexploitation, erode ecosystem services and, by extension, affect macroeconomic outcomes. The framework begins by assessing the biophysical impacts of human activities, including land conversion, emissions, and resource extraction, and translates these into quantifiable changes in ecosystem services. These changes are then linked to economic indicators of well-being and productivity. The model also incorporates policy mechanisms, such as payments for ecosystem services, targeted conservation incentives, and environmental taxation, which influence land use and resource management decisions. This integrated approach highlights the risks of excluding ecological dynamics from economic analysis, leading to underestimation of system-wide vulnerabilities. It also demonstrates that well-designed conservation and land-use policies can yield substantial long-term economic benefits while strengthening resilience to environmental shocks.

In a similar vein, and motivated by the recognition that conventional macroeconomic models tend to overlook the finite and fragile character of natural capital by assuming unlimited resource availability and infinite waste absorption capacity, the paper titled **Introducing Natural Capital in Macroeconomic Modeling**, by Nicoletta Batini and Luigi Durand, seeks to address this conceptual gap. The authors extend a standard neoclassical growth framework, akin to the Solow model, to explicitly incorporate natural resources and ecosystem services. The model distinguishes between renewable and non-renewable resources, capturing their regeneration and depletion

dynamics, intrinsic stock growth rates, and the ecological thresholds that constrain sustainable use. It also differentiates between notions of sustainability, comparing strong sustainability—where natural capital must be preserved or enhanced over time—with weak sustainability, which permits substitution between natural and human-made capital. Within this extended framework, Batini and Durand examine how policy instruments, including environmental taxation, property rights, and technological innovation, affect the evolution of natural capital and, by extension, macroeconomic performance.

The model demonstrates that excluding natural capital from macroeconomic analysis significantly understates the risks of economic and financial instability. Long-term economic growth depends on the preservation of biodiversity and ecosystem services, and their degradation can trigger adverse macroeconomic shocks and diminish overall welfare. The framework also shows that policies promoting sustainable resource use, such as conservation strategies, innovation in resource-efficient technologies, and secure property rights, contribute to more stable and resilient economic trajectories. Crucially, the analysis reinforces the importance of incorporating ecological constraints directly into macroeconomic modeling to avoid the long-run costs associated with biodiversity loss, resource depletion, and ecosystem collapse.

While renewable energy sources such as solar, wind, and hydropower are essential for reducing carbon emissions and addressing climate change, their expansion can inadvertently pose risks to biodiversity and ecosystems through habitat modification, pollution, and resource overuse. Motivated by this inherent tension, the paper **Biodiversity vs. Climate Risk Exposures of Renewable Energy Firms**, by Johannes Stroebel and Xuran Zeng, investigates the extent to which renewable energy companies are exposed to biodiversity-related transition risks and how these exposures influence financial outcomes and investor behavior. To examine this question, the authors analyze corporate risk disclosures, including 10-K filings, and compare the risk profiles of renewable and nonrenewable energy firms. They focus on key transmission channels, including land-use change, habitat disruption, environmental pollution, and resource extraction, all of which may harm biodiversity and generate regulatory or reputational repercussions. In addition, they study how financial markets respond to news about climate and biodiversity risk realizations, linking these responses to stock price movements.

The findings indicate that renewable energy firms report greater exposure to biodiversity risks than their nonrenewable counterparts, largely due to the ecological disruptions associated with project development. Although these firms benefit from lower exposure to climate transition risks, owing to their alignment with global decarbonization goals, their financial performance remains sensitive to biodiversity-related concerns. Empirical analysis of stock returns shows that renewable energy portfolios respond positively to news signaling progress on climate policy, reflecting investor optimism about climate mitigation. In contrast, these same portfolios underperform following news events highlighting biodiversity risks, suggesting that markets perceive such risks as material and adverse. The authors conclude that the large-scale deployment of renewable energy infrastructure, if poorly managed, may conflict with biodiversity preservation objectives. As such, explicitly incorporating biodiversity risk into investment and policy decisions is essential for achieving a sustainable and resilient energy transition.

The keynote lecture by Maximilian Auffhammer, titled **The Social Cost of Carbon—What’s New and Next**, offers a detailed overview of recent developments in the estimation of the Social Cost of Carbon (SCC), with particular attention to how advances in empirical economics, climate science, and discounting theory have reshaped the modeling tools employed in U.S. federal climate policy. Auffhammer traces the evolution of the SCC through improvements in integrated assessment models, including DICE, FUND, and PAGE, and explains how recent methodological innovations—such as probabilistic modeling of climate sensitivity, empirically grounded, sector-specific damage functions, and the explicit treatment of catastrophic tail risks—have led to more nuanced and robust estimates.

He notes that the current central estimate of the SCC, approximately USD190 per metric ton, reflects these technical advances, although substantial uncertainties remain. These include the specification of sectoral damages, geographic heterogeneity in climate impacts, and the challenge of modeling low-probability, high-impact outcomes. Auffhammer emphasizes the importance of further refinement through improved regional granularity, dynamic risk modeling, and more precise estimation of economic damages. He also addresses the normative debates surrounding discount rates and intergenerational equity, both of which significantly influence the SCC’s magnitude. Auffhammer advocates for continued research to enhance the credibility and policy relevance of SCC estimates, which

remain central to the design of effective mitigation strategies. He concludes that, while the SCC is a critical metric for aligning economic decision-making with climate objectives, its reliability and thoughtful application are essential to avoid the most severe consequences of unmitigated emissions.

The volume concludes with two papers examining the impacts of climate change and ecosystem service degradation from a multidisciplinary perspective.

The first one, **The Possibility and Plausibility of Large Macroeconomic Impacts from Climate Change**, by Marshall Burke, Mustafa Zahid, and Solomon Hsiang, explores whether the risk of catastrophic macroeconomic impacts has been systematically underestimated. Drawing on empirical evidence of severe climate consequences and ecological feedback mechanisms, the authors use global historical panel data to estimate the relationship between temperature variability and national economic growth. They uncover a nonlinear relationship in which countries with hotter climates suffer disproportionately from incremental warming. By combining these empirical estimates with climate model projections under various emissions scenarios, they simulate potential effects on both global and country-level economic output over the course of the twenty-first century.

Their analysis suggests that, by 2100, global economic output could decline by approximately 10 to 30 percent relative to a no-warming baseline. Under conservative assumptions that exclude lagged temperature effects, estimated impacts are around 10 percent. However, when accounting for lagged effects—which better reflect empirical patterns—losses could reach as high as 30 percent. These projections are considered plausible, as they fall within the range of historical growth fluctuations and are consistent with recent Bayesian forecasts of economic trajectories. While impacts vary across countries, some of the most affected regions, including parts of Africa and the Middle East, may face economic disruptions beyond their historical experience, raising significant concerns for growth, stability, and resilience in vulnerable economies.

The second and final one, **Through Drought and Flood: Past, Present, and Future of Climate Migration**, by Elías Albagli, Pablo García, Gonzalo García-Trujillo, and María Antonia Yung, investigates the historical role of climate variability in shaping migration patterns and projects potential future flows under a range of climate scenarios. The first part of the paper adopts a narrative approach centered on four

historical episodes: the collapse at the end of the Bronze Age (circa 1200 BCE), the decline of the Eastern Mediterranean civilizations (circa 1000 ACE), the Bholá cyclone and the Indo-Pakistani War leading to the formation of Bangladesh in 1971, and the Rwandan genocide and subsequent conflict in the Congo Basin between 1994 and 2001. Across these cases, the authors document that severe climate disruptions have historically triggered substantial outward migration, often mediated by social conflict, violence, regime change, and, in some instances, societal collapse.

In the second part of the analysis, the authors employ a panel data framework using combined climate, migration, and economic data from 154 countries between 1990 and 2020 to quantify the climate-migration relationship. They identify a highly significant, nonlinear association characterized by a U-shaped curve centered around a temperature optimum, with stronger nonlinearities observed in lower-income countries. Despite having experienced smaller average temperature increases to date, tropical countries have seen the highest rates of outward migration, driven by higher baseline temperatures and lower adaptive capacity due to limited economic resources. Using their estimated model, the authors simulate future migration flows under five IPCC emissions scenarios and one tipping-point scenario involving the collapse of the Atlantic Meridional Overturning Circulation (AMOC). Under moderate scenarios, migration increases modestly, but in the most extreme case, outward migration from tropical regions is projected to double. In the AMOC collapse scenario, where northern regions experience severe cooling, total global outward migration could rise from 200 million in 2020 to one billion by 2100, with much of the displacement originating from cold and temperate zones. The authors caution that these estimates may represent a lower bound, given nonlinear dynamics that are difficult to fully capture and the likely economic losses from climate damages, which would further constrain adaptive capacity.

In summary, the papers in this volume underscore the importance of adopting an integrated, multidisciplinary approach to address the risks posed by climate change and the degradation of ecosystem services. The seven research papers and two keynote lectures collectively demonstrate that fostering technological innovation, incorporating the value of natural capital into decision-making, embedding ecological and climate-related risks into financial oversight, and advancing coordinated policy frameworks are all critical for building resilient and sustainable economic systems. As environmental pressures continue to

intensify, the insights and strategies presented here offer a coherent roadmap for researchers, policymakers, and financial institutions seeking to preserve macroeconomic stability and ecological integrity in the face of accelerating climate change.

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