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A Complex System Perspective on the Economics of Climate Change, Boundless Risk, and Rapid Decarbonization

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A Complex System Perspective on the Economics of Climate Change, Boundless Risk, and Rapid Decarbonization[*]

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Abstract

Climate change stands as one of the most formidable challenges in the twenty-first century. Despite this, our understanding of the unfolding and interconnection of climate-related physical and transitional risks, and their implications for socioeconomic dynamics along various transition pathways, remains insufficient. This deficit of understanding echoes throughout the formulation of effective climate change policies. In this context, our chapter emphasizes the need for a comprehensive and interdisciplinary approach to address climate change. Such an approach must (1) credibly encompass the immense risks that global warming exerts on the Earth system; (2) account for the intricate processes of technical change and technology diffusion that are at the core of the low-carbon transition; (3) allow the percolation of risks and opportunities across sectors and regions; (4) account for behavioral change in consumption dynamics; and (5) allow testing of a wide range of climate policies and their robustness. Complex-systems science offers distinct vantage points for framing the intricate climate challenge. While outlining current research gaps, we argue that the current generation of climate–economy models rooted in complex systems provides a promising starting point to fill these gaps. We delve into a series of findings that evaluate the material impact of climate risks on economic and financial stability and explore alternative trajectories for policy implementation. Our analysis underscores the ability of complex-systems models to account for the extreme costs of climate change and the emergence of critical tipping points, wherein unmitigated emissions lead to free-falling declines in long-term growth and catalyze financial and economic instability. Given such findings, we argue that a complex-systems perspective on climate change advocates for stricter and earlier policy interventions than do traditional climate economy models. These policies can transform the seemingly antithetical objectives of decarbonization and economic growth in standard models into complementary ones. We assert that a combination of regulation and green industrial policies can nurture eco-friendly investments and foster technological innovation, thus steering the economy onto a zero-carbon sustainable growth pathway. These results challenge conventional precepts in the realm of cost-benefit climate economics and offer the building blocks for a more robust and realistic framing of the climate challenge.

Keywords: climate change, complex system, agent-based modeling, decarbonization, climate risk.

JEL codes: Q54, Q55, O44, C63.

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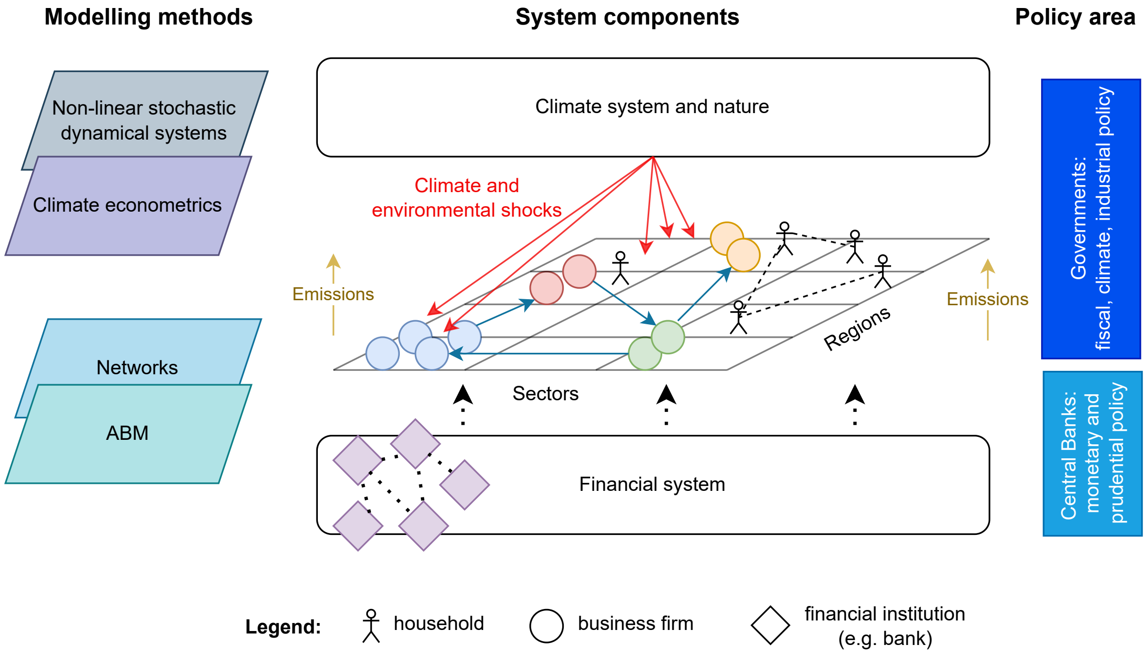
1. Introduction

Addressing climate change is one of the most daunting challenges of the twenty-first century. It requires a systemic turn in production and consumption modes at all scales. New technologies must be developed and deployed; novel sectors must rise, and established ones transform or be phased out. Different lifestyles must emerge, the capacity to adapt to unmitigable risks must be developed, and we must find a more conscious and respectful relationship between nature and human activities. Further, to avoid catastrophic and irreversible impacts on ecosystems and societies, all these processes must be timely and adequately sustained by regional, national, and global policy architectures. At the time of writing, the remaining carbon budget for a 50% likelihood to limit global warming to 2°C has reduced to 315 GtC, equivalent to around 28 years at 2023 emissions levels (Friedlingstein *et al.* 2023). For a target of 1.5°C with the same likelihood, only seven years are left. While natural scientists have made enormous progress in assessing the climate system and the risks it poses under uncontrolled emissions, much less understood are the socioeconomic effects of global warming and the strategies needed to rapidly decarbonize the world economy.

The traditional lens used to analyze the relationship between the climate and socioeconomic activities is at best grounded on a stylized representation of the basic elements: the economy, the process of growth, the carbon cycle, the damages induced by global warming, the means to decarbonize production, the role of states and governments (Pindyck 2013; but see Stern *et al.* 2022). The basic architecture was motivated by an interpretation of climate change as a simple externality created by greenhouse gas emissions. The implied solution boiled down to the determination of a desirable Pigouvian tax, internalizing the “costs” of emissions through a monetary incentive and restoring the welfare-maximizing equilibrium (Nordhaus 1992). After more than thirty years, a good deal of research in climate economics is still concerned with the same issue, adopts the same interpretation of global warming, and uses the same tools—somehow stretched to incorporate novel elements and evidence (e.g., new values for discount rates)—to provide ever-changing estimates of the optimal carbon tax (Barrage and Nordhaus 2024; Tol 2024). Though potentially helpful in building tractable relationships between extremely complex phenomena, these models grossly failed to understand the socioeconomic repercussions of climate change or provide clear policy guidance toward rapid decarbonization (Ackerman and Stanton 2012; Stern 2016; Stern *et al.* 2022). In his 2018 Nobel lecture, William Nordhaus advocated for a desirable global warming of about +3.5°C (Nordhaus 2019), in stark contrast with natural scientists’ worries and Intergovernmental Panel on Climate Change (IPCC) reports. Climate damages were underestimated by an order of magnitude with respect to most recent empirical evidence (Kotz *et al.* 2024; Palagi *et al.* 2022; Tol 2018), and policymakers have largely discarded the plea for carbon taxes as the silver-bullet climate policy (Peñasco *et al.* 2021). Motivated by these failures, alternative approaches to the economics of climate change have emerged in the last decade (see for example the discussion in Balint *et al.* 2017; Farmer *et al.* 2015; Stern *et al.* 2022). Many of them have implicitly or explicitly adopt a complex system perspective to inform the analysis of global warming, its sources, its effects in the short and long runs, and the range of remedies that should be considered to avoid or limit adverse impacts.

This chapter buils on these studies and advocates for a comprehensive and interdisciplinary approach to addressing the complex challenges posed by global warming. Such an approach must consider the intricate processes of technological change and diffusion, the fundamental drivers of economic growth, the structure of production and consumption across sectors and regions, and the basic statical properties of climate-related events. As Stern, Stiglitz, and Taylor (2023) put it, addressing global warming requires an economics of immense risk, radical changes, and urgent policy intervention. In this direction, a comprehensive framework (see fig. 1) is needed that addresses (1) large impacts and potentially irreversible dynamics induced by sector- and region-specific risks to nature and the climate; (2) the percolation of shocks across input–output networks of production, investment, and financing relationships; (3) emerging new technologies, firms, and sectors as fundamental drivers of the transition (and incumbents as obstacles to change); (4) the heterogeneity of behaviors and the determinants of their mutation; and (5) the possibility of jointly assessing public policies in their full complexity. Approaches rooted in complex-systems science—nonlinear dynamical systems, network models, and agent-based simulations—are uniquely positioned to integrate knowledge from different fields (such as climate, network science, machine learning, and evolutionary theories) and develop the necessary framework for a reliable economics of climate change.

Figure 1 - ***A complex-systems perspective on the economics of climate change, merging impact assessment and the design of mitigation pathways supported by public policies.***



First, we will discuss climate risks in the context of complex economies and outline the need to better integrate them into complex-systems modeling. Then we will delve into technological change as the core process behind any credible decarbonization trajectory before moving the focus to decarbonization, highlighting the contributions of agent-based and network models.

2. Climate Risks for Complex Economies

First and foremost, climate risks are those associated with the impacts of climate change. These risks—typically labeled as *physical*—are determined by the dynamics of the Earth system (see, e.g., Steffen *et al.* 2018) and can be either event-driven (acute) or associated with longer-term shifts in climate patterns (chronic). A key question that has rapidly gained momentum at the top of the policy agenda concerns how large these risks can be for modern economies, especially when accounting for tipping points and irreversible dynamics (Wunderling *et al.* 2024).

Modeling the impact of the weather on the macroeconomy presents significant challenges. Weather conditions are geographically clustered, can encompass a wide range of hazards (from floods and heat waves to droughts and compound events), and show return times (i.e. the average period between one event and another of equal or greater magnitude) that may shift abruptly with climate change. Further, the weather's effects on human activities depend highly on adaptation capacities, which vary widely among firms, households, regions, and societies. Consequently, physical risks inherently produce effects that are localized, strongly nonstationary, and heterogeneous across economic agents within the same affected region. These impacts can then propagate over time, across regions, and through economic networks such as supply chains and credit relationships. While traditional climate–economy models have focused on deterministic aggregate representations of climate damages and adaptation, models rooted in complexity science are naturally equipped to study propagation dynamics—thanks to their ability to incorporate heterogeneity, interactions, flexible scales, and bottom-up aggregation—and low-likelihood high-impact regime shifts—thanks to their nonlinear and stochastic nature (see Balint *et al.* 2017; Coronese and Luzzati 2024; Dawid and Delli Gatti 2018; Dosi and Roventini 2019; Farmer and Foley, 2009; Filatova and Akkerman 2024, this volume) and for a general introduction to the economics of a complex evolving system, Dosi, 2023).

Lamperti *et al.* (2018) developed the Dystopian Schumpeter Meeting Keynes (DSK) agent-based integrated assessment model to study the macroeconomic effects of climate-related shocks on economic dynamics over the short, medium, and long runs. The DSK model is the first attempt to employ a genuine bottom-up approach to assess climate damages in complex economies. It models the impacts of changing climatic conditions as micro shocks hitting workers' labor productivity and firms' energy efficiency, capital stock, or inventories. To do this, it introduces a stochastic microscopic damage-generating function, which models the direct impact of the weather on individual economic activities. At the end of each period, a random sample of climate-related shocks—which mirrors both acute events (e.g., floods) or chronic exposure (e.g., gradual temperature increases)—is constructed to affect agents though a multiplicative process. In particular, in most applications, the microscopic damage-generating function takes the form of a beta distribution (from which shocks are sampled), whose location and scale parameters are calibrated to reflect the shifts in likelihood of impacts due to global warming and its variability (Coronese *et al.* 2019; Kiley 2024). Simulating the unfolding of climate-economy interactions along carbon-intensive futures—as mirrored by business-as-usual scenarios compatible with a Representative Concentration Pathway 8.5 delivering global warming at the end of the century beyond 3°C—returns way higher economic risks than those of the standard impact assessment literature. The century-long growth in income is about one-third of the counterfactual scenario without global warming, but, more relevant, climate change is found to affect the short-, medium-, and long-run growth trajectory of the economy, rather than simply cutting the level of gross domestic product. Further, the negative impacts of climate change are magnified by the financial system via firms' bankruptcies possibly triggering instability in the banking sector (Lamperti *et al.* 2021, 2019). Results provide evidence of a substantial lack of isomorphism between the effects of micro- and macro-level shocks, as is typical of complex systems. Different types of shocks exert different effects on output growth, the unemployment rate, financial instability, and the likelihood of economic crises. Most relevantly, simulating the DSK model shows that uncontrolled warming may induce emergent tipping points in the dynamics growth, which appear as shifts in the growth trajectory of the economy toward a regime characterized by stagnation and high volatility in which the economy locks in even if emissions are (too lately) mitigated (Lamperti *et al.* 2019; Tàbara *et al.* 2018; see also Wunderling *et al.* 2024).

A micro-to-macro approach to the macroeconomic assessment of climate change has been incorporated in other models beyond DSK, showing that weather events may affect the aggregate economy by altering the agglomeration dynamics of production activities (Taberna *et al.* 2022; Coronese *et al.* 2023), as well as the uncertainty of business cycles (Bazzana *et al.* 2024). However, there is a relevant dimension that most macroeconomic agent-based models grossly miss that is relevant to study the propagation of climate impacts: region and sector cross-dependencies in production and consumption. Indeed, different sectors have different exposure to the weather (e.g., construction vs. information and communication technology), and climatic conditions are most often region (or even location) specific. While traditional approaches have focused on computable general equilibrium models to study such dynamics, there is no ex ante reason to believe that imbalances in production and trade across regions and sectors are fully solved by relative prices, especially when large weather events disrupt businesses, infrastructures and credit relationships. By contrast, production network models rooted in complexity science offer flexible environments to study the out-of-equilibrium, scarring, and path-dependent adjustment of a “shocked” input–output economic structure, at least in the short run (Di Noia *et al.* 2024; Poledna *et al.* 2018; Willner *et al.* 2018). These analyses are crucial to inform policymakers about the most vulnerable (and resilient) parts of the production system and to evaluate the shape, length, and geographical heterogeneity of the postdisaster recovery.

Beyond physical risk, there is another large class of climate-related risks whose assessment deeply benefits from a complexity-based perspective. *Transition risks* are business-related risks that follow societal and economic shifts toward a low-carbon and more climate-friendly future. The systemic turn to a low-carbon economy will inevitably produce winners and losers, and assessing where opportunities and risks are created—and how they percolate in the economy—is pivotal to guide decarbonization policies. For instance, studies embracing network analysis have shown that aggressive shifts toward low-carbon energy sources may create stranded assets, underutilized capital stocks, and losses in financial actors percolating within the financial system and back to the real economy (Battiston *et al.* 2021; Cahen-Fourot *et al.* 2021; J.-F. Mercure *et al.* 2018). Using different macro ABMs, Ciola et al. (2023), Kremer et al. (2024), and Fierro et al. (2024) pointed out that transition imbalances most likely induce adverse distributional effects calling for stabilization and counterbalancing policies. Indeed, the materiality of transition risks largely depends on how the transition is initiated and managed. Wieners *et al.* (2024) rely on the DSK agent-based model to show that—in a complex evolving economy in which economic agents are relatively insensitive to price signals—decarbonization may create either large frictions or opportunities spurring growth and job creation, depending on the actual policy mix used to foster the transition. And, last but not least, successfully mitigating climate change will have an enormous impact on living conditions, health, life expectancy, and social welfare in general (Carleton and Hsiang 2016; van Daalen *et al.* 2024).

Though they are mostly treated as stand-alone categories, there is increasing evidence that physical and transition risks are strongly intertwined. For instance, Lamperti *et al.* (2020) use the DSK model to show that the low-carbon transition of the energy sector may be affected by climatic conditions. Indeed, when climate damages are factored in, the likelihood of the green transition depends on how climate change affects agents in the economy. Global warming may lead to increases in energy demand that—at the prevailing energy mix in most economies—may favor carbon-intensive technologies and delay the transition. A comprehensive assessment of climate risks would need to incorporate both physical impacts and transition imbalances to design robust decarbonization trajectories and help actual policymaking.

Overall, merging methods in complexity science (e.g., network and agent-based models) with robust evidence from climate science and climate econometrics—which would deliver a realistic picture of future climates and their micro-level impacts—appears to be a promising avenue to solve current modeling gaps and build the next generation of climate-economy models.

3. Technological Change as the Basic Building Block of the Low-Carbon Transition

Reducing carbon emissions to limit global warming to 1.5°C above preindustrial levels also requires the application of climate technologies that are not yet available. Many sectors—from freight, water, and air transportation to metallurgy and cement production—still rely on fossil fuels, with green alternatives either nonexistent or unavailable on the necessary scale. To give a sense of the current technological gaps, consider that 99% of the mitigation scenarios employed in IPCC reviews that comply to the 1.5°C target rely at least to some extent on technologies that are still at the testing stage and need time, research, and financial support to reach maturity and adequate diffusion. Overall, a wide range of climate-friendly technologies still need to be discovered, developed, and upscaled. It is unrealistic to expect that markets alone will coordinate all the economic actors involved through price signals. Governments and public agencies will play a major role, and they need to build the necessary state capacities to support and guide the process, eventually creating and shaping markets rather than following them (see Mazzucato *et al.* 2015 and Dosi *et al.* 2023).

Evolutionary economics and complexity science are in a unique position to offer the theoretical background and the modeling tools to understand the process of technical change that is needed to operationalize the low-carbon transition and to assess the drivers and barriers to its unfolding.

Theories on the emergence, development, and shifts of technological paradigms and technological trajectories can provide the bulk of the architecture (Dosi 1982, 2023). Indeed, contrary to what the majority of climate-economy models assume (Mercure *et al.* 2019; Pasqualino *et al.* 2024), technologies do not develop from scratch, nor they are pushed by markets. Rather, they emerge from the accumulation of technical knowledge and the development of routines embedding it. In this process, a novel technological paradigm stems from the interplay among scientific advances, economic factors, institutional variables, and unsolved difficulties on established technological paths (Dosi 1988, 1982). The history of a technology is then contextual to the history of the industrial structures associated with it. The emergence of a new paradigm is often related to novel companies arising through Schumpeterian creative destruction, while its establishment typically relates to a process of oligopolistic stabilization. The direction of technological change is set by the emergence of industrial structures and technological paradigms supporting a given technological trajectory. While the unfolding of a technological trajectory makes the pattern of innovation more incremental and predictable, the exhaustion of an established path is associated with large and irreducible uncertainty, which can be only partially mitigated by policy interventions and is only solved by the emergence of the next paradigm (Dosi 2023).

First and foremost, the process of decarbonization is linked to the emergence of an ensemble of technological paradigms and trajectories enabling the full development and diffusion of alternative technologies in currently carbon-intensive sectors. In stark contrast, traditional models employed to assess mitigation pathways (including the so-called process-based integrated assessment models used in IPCC reviews) overlook the role of industrial structures, institutions, radical uncertainty, and path-dependence. They tend to depict mitigation as an optimal process of adopting available technological options (eventually ameliorating over time at exogenous and fixed rates) operated in perfectly competitive markets and guided by policies altering their costs—typically, a carbon tax. In such a context, technological change is mostly limited to walking through learning curves. Indeed, these models have little to say about how different low-carbon technologies can be developed and diffused, which is a major current challenge.

By contrast, agent-based and system dynamics models that take technical change seriously have existed for decades (Dawid 2006). These models embed the theoretical setting (briefly) described above into realistic simulations of the evolution of technologies and industrial structures, shedding light on the emergence of novel technological trajectories and novel sectors, the diffusion pattern of innovations, and the possible lock-ins in inferior technologies. Further, macroeconomic models rooted in the evolutionary tradition put technical change at the core of long-run growth (Dosi and Roventini 2019). In this context, the economy's development is mostly set by the direction of technological change, which in turn coevolves with the emergence of firms, sectors, coherent demand, and the institutional setting (Dosi *et al.* 2022, 2022). As such, the direction of innovation can be influenced by public policies and, possibly, predicted (especially within technological trajectories; see also Farmer and Lafond 2016 and Lafond 2024, this volume).

All these elements should be gradually translated into macroeconomic models for the transition to provide a realistic assessment of the available trajectories for decarbonation, including their drivers and obstacles, and to assess if, when, and how full decoupling between growth, emissions, and resource use is viable. Currently, this is the most promising avenue to study the long-run prospects of growth, its sustainability, and the eventual consequences of postgrowth trajectories (Stern and Stiglitz 2023). As we shall see in the next section, such a process has already started and has delivered successful results.

4. Modeling Climate Change and Decarbonization through Agent-Based and Network Models

Agent-based models (ABMs) have increasingly been recognized as promising alternatives to traditional climate-economy frameworks, not only for assessing climate risks but also for designing realistic and robust mitigation pathways that align with ambitious climate targets (Balint *et al.* 2017; Farmer *et al.* 2015; Stern 2016). These models offer at least five key distinctive advantages: (1) they typically account for endogenous technical change and the diffusion of new technologies; (2) they incorporate heterogeneity in consumption dynamics and behavior change; (3) they naturally address distributional issues, which are mostly overlooked in other modeling approaches; (4) they can easily incorporate climate impacts at the micro level; and (5) they flexibly allow for a wide array of policies and their combination, from price incentives to regulation on quantities, from relative standard to nudges (see also Savin *et al.* 2023).

Several ABMs have been developed over the past decade, providing valuable insights into the complex processes underlying the transition to a low-carbon economy (see Balint *et al.* 2017; Castro *et al.* 2020 for two reviews) and highlighting key gaps to be filled in future research.

The DSK model—the first agent-based integrated-assessment model—was developed to account for the coevolution of the economy and the climate at global scale, allowing for endogenous and path-dependent technological change, the diffusion of low-carbon technologies in multiple sectors, the dynamics of electrification and the phasing out of carbon-intensive capital stock (see Lamperti and Roventini 2022 for a review). The model - which has undergone a detailed empirical validation (Martinoli et al. 2024) - accommodates climate, innovation, industrial, fiscal, monetary, and prudential policies. Using DSK as a policy simulation laboratory, Wieners *et al.* (2024) have shown the fallacy of carbon taxation as the major climate policy instrument. Indeed, while carbon taxes are often seen as the key tool for reducing greenhouse gas emissions, their effectiveness and consequences are far from straightforward. The results show that rapid and uncoordinated implementation of high carbon taxes can lead to significant economic disruptions, including sharp increases in energy prices, reduced investment, rising bankruptcy rates, and potential spikes in unemployment. Indeed, as economic agents behave through adaptive routines, their sensitivity to relative prices is far less pronounced than equilibrium-based models rooted in the expected utility framework assume. As a consequence, the price signal needed to guide a transition might be excessively high not to exert adverse and potentially long-lasting effects on the macroeconomy (on this matter, see also the empirical results of Känzig 2023). And this holds when carbon taxes increase over time, as suggested by the cost-benefit literature à la Nordhaus (2019) or in the form of rebates to households and firms. These results suggest that relying solely on carbon taxes to drive decarbonization is not only insufficient but potentially harmful to economic stability. To the contrary, complexity-based climate-economy models robustly show that navigating the transition more effectively requires a combination of policy approaches. In the DSK model, this translates into a policy mix focused on green industrial policies (Wieners *et al.* 2024; Lamperti *et al.* 2024). Indeed, regulatory measures, such as command-and-control policies, can set clear standards and enforce compliance across different sectors, ensuring that emissions are reduced consistently and systematically moving the system toward different technological trajectories. These regulations can be complemented by green industrial and innovation policies that promote the development and adoption of sustainable technologies. By fostering innovation and guiding investment toward green industries, these policies can help build the foundation for a sustainable economy without placing undue strain on incumbent firms, which need to rapidly shift their technology and electrify production. While carbon taxes can still play a role in this policy mix, their application should be more strategic and measured: a moderate carbon tax could be levied to generate revenues for funding the transition to a low-carbon economy. This approach would help neutralize the impact of climate policy on the public budget while providing an incentive for businesses and consumers to reduce their carbon footprints. The policy mix designed with the DSK model turns decarbonization and sustainable economic growth into complementary objectives answering the plea of Stern and Stiglitz (2023), for which the only possible story of economic growth for the twenty-first century is a green growth story. These results align with the broader evidence coming from the complexity-based literature on the centrality of industrial policies to effective decarbonization (see Dafermos and Nikolaidi 2019; Lamperti *et al.* 2021; Mercure *et al.* 2018; Rengs *et al.* 2020; Nieddu *et al.* 2024).

Moreover, the transition must be managed in a way that accounts for the dynamic interactions between different sectors of the economy (see also Andres and Dumas 2024, this volume). The shift to a low-carbon economy will affect not just energy production and consumption but also industries such as transportation, manufacturing, and finance. A holistic approach that considers these interconnections is essential for ensuring a smooth and sustainable transition. In the aftermath of the 2007 financial crisis, macroeconomic ABMs have been extended to incorporate real-financial interactions (Fagiolo and Roventini 2017; Farmer and Foley 2009). Further, recent developments in input-output network modeling have shown the centrality of accounting for microscopic entities and their relationships to correctly capture the structure of production and consumption activities (Pichler et al. 2023, Diem et al. 2024). Indeed, the sectoral dimension is often too coarse. Thanks to such developments, ABMs and network models are ideally situated to offer the necessary framework to study the percolating risks and opportunities that can materialize during a rapid decarbonization process (see fig. 1). In that, one key area in which future development is needed concerns extensions to multiple energy sources and the inclusion of additional low-carbon technologies (e.g., negative emission technologies and carbon removal methods, which are increasingly represented in computable general equilibrium climate-economy models). Indeed, for most climate-economy ABMs to generate mitigation pathways that meet the inclusion criteria for IPCC reports, a more fine-grained representation of the transition is needed in most emission-intensive sectors (e.g., power, transportation, buildings, industry; see also Del Rio Chanona et al. 2024, this volume). Further, these developments must integrate into a multiregion framework to differentiate the trajectories of technological and structural change across key areas and to accommodate international flows of technologies, labor, and funds within the design of climate policy. To gain policy relevance, this should be a key objective for the next generation of climate-economy ABMs.

Another crucial factor in accelerating the transition involves behavioral changes, public attitudes toward policies (such as policy credibility), and how these attitudes spread through society. This becomes even more significant in light of the growing body of evidence showing the vast disparity in emissions across different income and wealth levels (Chancel 2022). Agent-based and network models have a long-standing tradition of studying how individual behaviors emerge, adapt, survive, or cease in an ecology of interacting entities. For example, they have proved a powerful tool to represent the complexities and behavioral aspects of energy demand. By contrast, traditional climate-economic models struggle to account for heterogeneity and change in households' and firms' behavior. Notwithstanding such "natural" advantages, macroeconomic ABMs employed to study the transition tend to miss elements such as heterogeneous consumption patterns, behavioral changes in energy use, drivers of adoption of sustainable transportation modes, and changing attitudes toward public policies. Though exceptions exist (see, e.g., D'Orazio and Valente 2019; Rengs *et al.* 2020; Safarzyńska and van den Bergh 2017), future research should better integrate climate-economy modeling with household heterogeneity (e.g., social classes), changing consumption patterns, and consumers' views on the credibility of future policy (see, e.g., Campiglio *et al.* 2024)). A deeper understanding of the evolution of demand for polluting products would open the door to coupling climate policies targeting the supply side of the economy with demand and investment patterns (on the importance of altering current consumption regimes, see IPCC 2022; Lamperti et al. 2025). Along these lines, policies addressing distributional issues could be designed to be synergic to emission mitigation (Guzzardi et al. 2023).

In summary, assessing the conditions that lead to successful and unsuccessful transitions requires integrating many elements, including climate impacts, a rigorous process of technical change, sufficient sectoral disaggregation, and behavioral changes determining the state of demand, that are overlooked by traditional analyses of decarbonization pathways. Theories, methods, and models rooted in complexity science are already filling these gaps. The next generation of climate–economy models can complete the process by integrating elements that are currently spread over different fields and applications in a coherent and synergic novel family of platforms.

5. Conclusions

We have provided a complex-systems perspective on the economics of climate change and its currents gaps and highlighted the need for a complex systems approach to address the multifaceted challenges of climate change. Traditional economic models fall short in capturing the extreme costs of climate change impacts, intricacies of technological change, sectoral dynamics, the distributional roots of carbon emissions, and the required policy combinations to deliver sustainable growth. Hence, we advocate for the integration of complex system science, particularly agent-based and network models, to provide a more realistic and comprehensive understanding of the climate-economy relationship. These models are better equipped to simulate the emergence of new technologies, the percolation of risks across sectors and regions, the drivers and obstacles of behavioral change, and the impact of different ensembles of policies, ultimately guiding more effective and robust climate policy combinations. Looking at climate change from the lens of complex systems provides an interdisciplinary framework that can estimate the huge costs of climate change inaction and the many benefits stemming from the decarbonization of the economy. In a complexity framework, timely and stringent climate policies can support the fast-decarbonization pathway required to stay well below 2°C while avoiding transition risks and fostering long-run sustainable growth. Further, such a perspective allows the analysis of the coevolution of the techno-economic domains and social dynamics. A complexity perspective allows the full appreciation of the possibility that continuing—rather than transforming—current trends could lead into the abyss the entire humankind.

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