Accounting for finance is key for climate mitigation pathways

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The financial system, the ecosystem of investors (e.g., banks, investment funds, insurance), markets, and instruments, is often considered to play an enabling role in climate mitigation pathways to a low-carbon transition (*1*). But it can also have a hampering role, e.g., if investors' perceptions of low risk from a missed transition and low opportunities from a transition fail to trigger a reallocation of capital into low-carbon investments. This increases the chance of the transition not occurring within the time window required to stabilize the climate or occurring in a disorderly fashion. But investors, who can influence the realization of climate mitigation pathways, themselves rely upon estimates of climate mitigation pathways from process-based Integrated Assessment Models (IAMs)(*2*). And IAMs do not model the financial system nor investors' decisions, thus the feedback loop between the financial system and mitigation pathways is not taken into account by the IAMs nor by the finance community. This limitation to our understanding of the dynamics and the feasibility of the low-carbon transition weakens the ability of IAMs to inform policy and investment decisions. We propose a framework to capture the interdependence between investors' perception of future climate risk, depending on the credibility of climate policies, and the allocation of investments in the economy.

Climate mitigation scenarios

Climate mitigation pathways are constrained by the laws of physics (e.g., cumulative CO_2 emissions leading to global warming levels) and by technological constraints (e.g. technological efficiency, limits to speed of technology deployment). Process-based, large-scale IAMs are used to develop long-term emission projections and socio-economic scenarios assessed by the IPCC (*5*,*6*). Scenarios are constructed to suggest how to reach given targets in terms of cumulative emissions (and thus in terms of carbon budget) at 2100, which translate into temperature targets with associated probabilities. The IAM literature, assessed by the IPCC *(1),* produced a set of archetypical climate mitigation scenarios representing the most distinct features of how the transition could happen in the next decades. This is where the notion of risk is key. While investors' preferences differ in terms of risk aversion and investment strategies, they all make investment decisions based on their assessment of risk.

In 2019, the Network of Central Bankers and Supervisors for Greening the Financial System (NGFS), a global platform of over 80 financial authorities, recognized that climate change poses new risks for citizens' investments and savings. It recommended a climate risk assessment of financial portfolios using several high-level scenarios (*3*), including: (i) an *orderly transition*, in which climate policies are introduced early and predictably and climate risks are priced in by financial markets; (ii) *a disorderly transition*, in which the impact of climate policies is not (fully) anticipated by investors. In the first case, firms have time to plan ahead and investors to reallocate capital gradually. In the second case, high-carbon firms and investors face losses that can trigger market instabilities and costs for society as a whole. Note that high-carbon firms would lose out in both situations, and more so in the disorderly scenario. In contrast, low-carbon firms would benefit in both situations, but not necessarily more in the disorderly scenario.

In order to translate these scenarios into quantitative trajectories of economic variables, the NGFS and a growing number of investors already use the output of process-based IAMs as an input for climate financial risk analysis (*4*). These scenarios, describing what the world might look like several years from now, have the power to shift markets' expectations today, because they are endorsed by the NGFS and large investors. It is thus critical to understand if these scenarios for potential tomorrows could lead, unintentionally, to insufficient investments today, due to their not accounting for the role of financial actors themselves. Our framework addresses this challenge and allows to derive scenarios that complement the current IPCC and NGFS scenarios, strengthening climate financial risk assessment.

Firms and consumers' responses to climate policies are endogenous to the IAMs and have been long investigated. But the ways in which investors' responses to climate policies affect the outcome of those policies has not been investigated in IAMs and is not well understood. Indeed, IAMs (including large-scale computable general equilibrium models (*7*)) consider "finance" only to the extent that firms' access to financing is assumed to be available at no cost and with no limits (*8*). They overlook that financing is provided by investors based on assessed risk, resulting in non-zero financing costs and limits on funding. IAMs include no actors (e.g. banks) that can decide to grant loans to firms, nor actors (e.g. insurance firms, pension funds) that can decide to invest (or not) in stock market shares of firms. This leads to the opportunity to interface IAMs with models where investors carry out a risk assessment.

An enabling or hampering role of the financial system

Consider a utility firm that seeks financing to shift its power plants from high to low-carbon technologies. If a bank perceives the strategy as less (more) risky than staying on high carbon technologies, because the climate policy, e.g. a carbon price, is perceived as credible (non-credible), it will soon charge a lower (higher) interest rate on the loan, thus facilitating (delaying) the firm's technological conversion. In general, if investors perceive high risk from a missed transition, and high opportunities from a successful transition with credible climate policies (*9*), they adjust their expectations. They thus reallocate capital into low-carbon investments early and gradually and can even anticipate the policy impact, as described by the notion of climate sentiments (*10*). This "enabling" behavior facilitates the transition, because it leads to smoother adjustments of the economy and of prices. If, in contrast, investors' perception goes in the opposite direction, they react late and suddenly. This "hampering" behavior makes the transition more costly for society, because it can lead to abrupt reallocations of capital and price adjustments.

The enabling or hampering roles of the financial system can explain how the orderly and disorderly transition emerges from the interplay of policy timing and investors' reactions. Overall, the presence of the financial system may induce a path dependence in the complex dynamics leading to lock-in effects similar to those described in models of technology diffusion. In particular, transition trajectories could differ from those described by IAMs' scenarios because IAMs only consider technology cost and not the financing costs to deploy such technologies, nor investors' reactions. For instance, investors could interpret NGFS scenarios of orderly transition as a situation in which high-carbon firms are only slightly more risky than low-carbon ones, because firms can adjust their technology mix and spread over time losses arising from stranded assets, i.e. unusable high-carbon installations (*11*). Driven by this risk perception, investors could play a hampering role and only reallocate capital from high to low carbon firms to a limited extent. It is not guaranteed that this level of reallocation is sufficient to fund investments in low-carbon energy that this scenario assumes; a low-risk perception induced by the orderly scenario could make the scenario unfeasible in the real world.

In contrast, investors could interpret a scenario of a disorderly transition as a situation in which high-carbon firms become substantially more risky than low-carbon ones, following the introduction of stringent carbon prices. For instance, high-carbon energy firms have an incentive to delay their own conversion, but, due to increasing public and investors' demand, politicians could eventually find an agreement to introduce stringent climate policies. Due to the opposing interests in the negotiation, this could happen at the last moment. Investors who want their portfolio to withstand such an outcome, could play an enabling role and start to demand a higher interest rate from high-carbon firms well before the policy introduction. They would reallocate capital to low-carbon firms in order to hedge the risk (if they continue to have a preference for lower risk). Thus, the capital reallocation, driven by risk perception, could lead to investments in low-carbon firms that increase earlier and at higher levels than those assumed in the scenario, leading to larger mitigation opportunities. Furthermore, the financial feedback on firms' investment decisions can also lead to cascading effects in the economy. To some extent, this is precisely what the disorderly scenario is meant for: to allow for an assessment of risk by investors in order to hopefully avert the realization of the scenario itself. This should not surprise, in the same way that requiring buildings' owners to consider fire scenarios is ultimately to avoid the adverse scenario. Possible inconsistencies between the investment levels in the original IAMs' scenarios and those resulting from the role of the financial system motivate the need for a new framework to connect climate mitigation scenarios and financial risk assessment in a circular way.

Connecting climate mitigation scenarios and financial risk assessment

The use of IAM scenarios to assess climate-related financial risks has been introduced by academic work on the climate-stress test of the financial system (*12*), and in recent applications to central banks' data (*13*). It consists of translating IAMs' output trajectories across technologies (e.g. fossil fuels and renewables) and scenarios into financial shocks on investors' portfolios. Combined with financial network models it also captures the amplification of shocks through financial interconnectedness and the implications on individual and systemic financial stability. We refer to this approach as the climate financial risk model (CFR). In IAMs, the decision of firms on how many energy plants of a given technology to build is determined by the carbon pricing. The financing costs and the fact that they vary with the risk attributed to technologies by investors is not taken into account, but can be obtained from a CFR model.

We propose a general framework (Figure 1) to link IAMs and CFR in a circular way, which can be embodied with different choices of specific IAMs and CFR models. The IAM module generates sets of climate mitigation scenarios, which are then used by the CFR to model how investors assess the financial risk of high- and low-carbon firms along the IAMs trajectories. If investors assess a higher risk for high-carbon firms, they demand higher interest rates on loans, and higher yields for bonds, in order to provide funding. They may also divest from some high-carbon firms to reinvest in low-carbon firms in order to balance their portfolio risk. The resulting trajectories of financing cost across low- and high-carbon firms are fed back to the IAMs in order to update the respective mitigation scenarios, thus closing the loop between the IAM and the CFR.

Figure 2 illustrates in a stylized form how such IAM-CFR scenarios can interplay between the role of the financial system (enabling or hampering) and the timing of the climate policy introduction, the latter being identified by the IPCC as a key dimension of climate mitigation. We condition the analysis to a temperature target of 2°C, in line with the Paris Agreement, but other scenarios can be analysed. Based on the IPCC and NGFS scenarios, we consider two options for the timing of policies. The immediate case focuses on 2020 (based on (*1)*), but results would be similar for 2021 or 2022. The delayed case focuses on 2030, since a transition that starts later than 2040 is considered not compatible with the 2°C target. All IAMs share the general result that, in a transition scenario that achieves a 2°C target, the output (energy production) of high-carbon activities starts to decline at the introduction of the policy, and the reverse applies for low-carbon activities. While quantitative details of output trajectories vary across IAMs, the solid curves in Figure 2 represent this common stylized behavior. In the enabling cases (Figure 2, top panels), investors start to demand higher interest rates for high-carbon firms at the introduction of the policy, or even earlier (the reverse for low-carbon firms). In the IAM-CFR scenarios, output of high-carbon firms must be lower than in the original IAM-only scenarios where only the carbon tax is considered (the reverse for low-carbon firms). This is due to financing costs, which are additional to the carbon tax and enhance the differences in profitability of firms across technologies. Accordingly, the value of assets of high-carbon firms decrease gradually and those of low-carbon firms increase gradually.

Investors' expectations are the key feature that sets the system to an enabling or a hampering role of the financial system. Because expectations are subject to herding dynamics whereby investors try to guess each other's next move, a stampede can occur unexpectedly (e.g., the 2008 subprime mortgage crisis). In the hampering cases (Figure 2, bottom panels), investors delay to revise their expectations, but then expectations change suddenly. There are several examples of how a collective adjustment can occur suddenly (e.g., the 2008 subprime mortgage crisis). This results in output trajectories that increase (or decrease) at a faster pace than in the cases without CFR as trajectories have less time to meet the same carbon budget. Financial asset values also adjust suddenly. The adjustment has to occur before 2040, otherwise the 2°C target is missed.
In the NGFS scenarios, the orderly vs. disorderly character of scenarios is assumed, independently of the role of the financial system. Here we show two cases where the financial system can largely modify the outcome of those scenarios. First, an immediate transition to 2°C is classified in the NGFS scenarios as orderly. If, however, the financial system plays a hampering role (bottom left panel), the transition is delayed in time and there are large and sudden financial value adjustments. These features threaten financial stability and would be more consistent with a disorderly scenario. Second, a delayed transition to 2 °C is classified there as disorderly. If the financial system plays an enabling role (top right panel), the gradual price adjustments along the

trajectory would be more consistent with an orderly NGFS scenario. Finally, a disorderly transition could also lead to higher risk than described in NGFS disorderly scenario, if the financial system plays a hampering role. Neglecting the role of the financial system could thus lead to overestimate or underestimate risk across NGFS scenarios.

Conclusion and policy implications

Our approach opens the way to new understanding of risks and opportunities associated with the low-carbon transition. By conditioning the investment decision to the credibility of climate policy scenarios, we consider the role of the financial system as enabling or hampering the low-carbon transition. This could reverse the ordering of costs and benefits of climate mitigation policies, which are currently distorted by not considering the financial system.

Such analyses can provide new insights on the implementation of fiscal policies, such as carbon pricing and the phasing out (in) of fossil fuel (renewable energy) subsidies. Neglecting the role of finance implies that a projected carbon price schedule could miss the emissions target because the mitigation scenario does not necessarily imply a risk perception by the financial system that leads to the investment reallocation assumed by the scenario. Similarly, plans for phasing out carbon subsidies have an impact on the financial system risk perception of high carbon technologies. Thus, our framework could help the IPCC community to revise their carbon price projections obtained from climate mitigation models in order to make them more consistent with the role that the financial system plays.

Our framework could also support financial authorities in encouraging investors' assessment of climate-related financial risk. The IAM-CFR scenarios would limit the underestimation of financial risk in climate stress-test exercises. Accounting for the role of the financial system also has implications for criteria used by central banks to identify eligible assets in their collateral frameworks and purchasing programs. Furthermore, our results shed light on the importance for financial authorities to monitor and tame the possible moral hazard of the financial system in the dynamics of the low-carbon transition.

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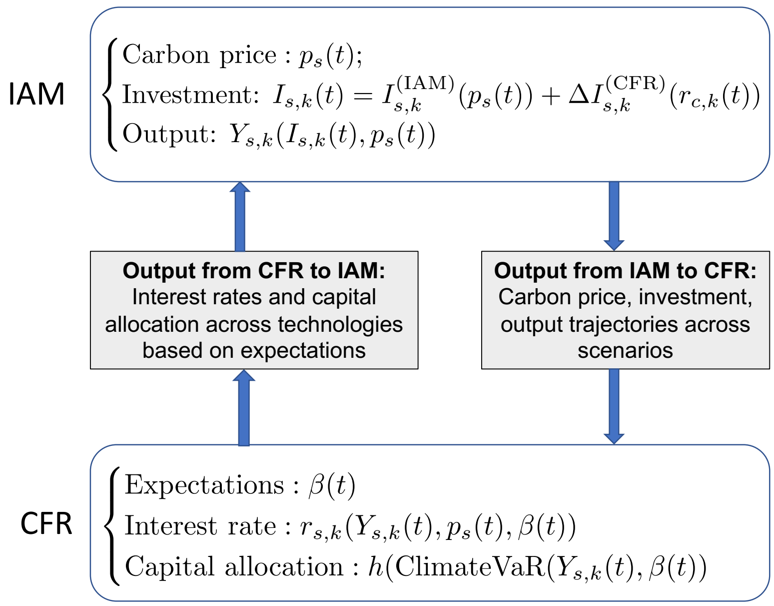

Figure 1. The framework to link IAM and CFR. *An IAM first generates a set of climate policy scenarios, describing trajectories over time (t) of output for each country (c), economic activity (s), and energy technology (k; e.g. coal-based vs renewable-based electricity). IAM output are related to specific economic activity and technology. For instance, the electricity produced by a utility company from wind. Investments represent the monetary value (e.g. in US $) of the investment in a specific economic activity and technology. Output Y and carbon price p computed by the IAM are then fed into the CFR to compute interest rates r for firms with different technologies (e.g., low/high-carbon), conditioned to the scenarios and investors' expectations* $\beta(t)$ *on policy credibility. Output impacts also on conditioned Climate Value-at-Risk (Climate VaR), i.e. expected loss for investors in the tail of the distribution. In turn, Climate VaR and expectations determine investors' decisions on capital allocation, i.e. the share of capital invested across technologies. Results of the CFR are then fed back to the IAM that can now account for diversity in financing cost across technologies. The cycle then repeats, with the IAM computing a new set of climate policy scenarios that account for the adjustments of interest rates across low/high-carbon firms and the funding decisions of investors.*

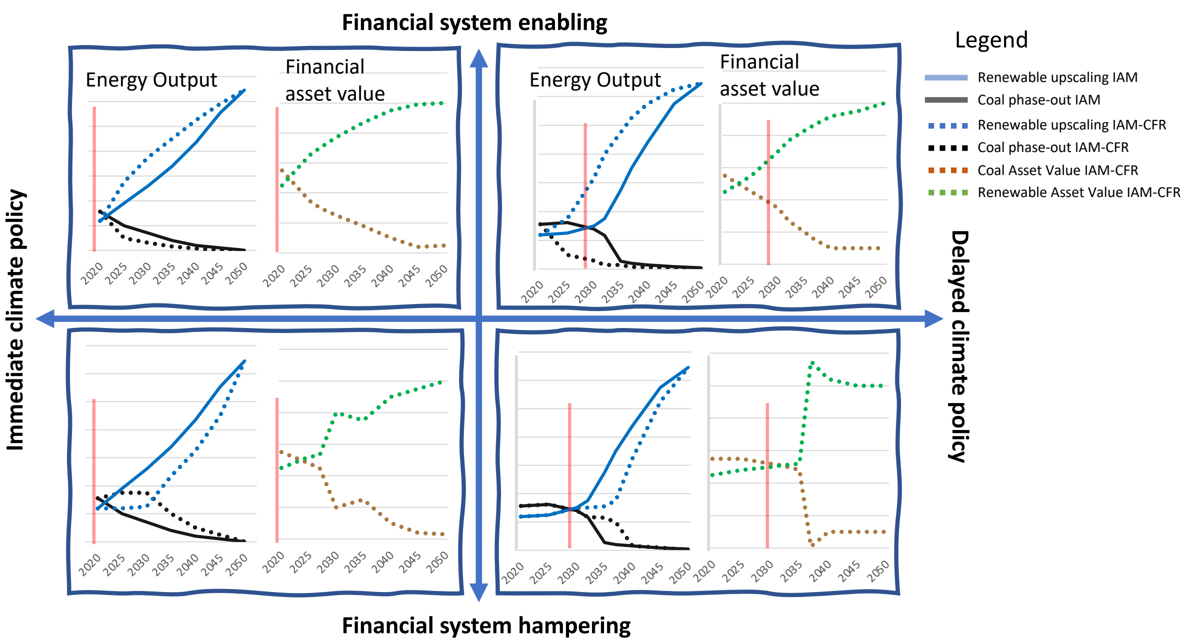

Figure 2. Interplay between the financial system and the timing of climate policy introduction. *Four main transition scenarios are shown with temperature target of 2°C. Solid curves are the same in top and bottom panels and represent stylized trajectories from existing IAM scenarios of electricity production from coal (black) and renewable energy (blue). Left panels reflect immediate policy introduction (2020 in current IPCC scenarios) and gradual increase/decrease of IAM electricity production. Right panels reflect delayed policy introduction (2030); IAM electricity production curves remain flat until 2030 and then increase/decrease more steeply than in the immediate case. Dotted curves represent stylized output electricity production and asset value trajectories from the IAM-CFR framework. Top and bottom panels reflect a financial system that enables or hampers the low-carbon transition, respectively. The difference between solid and dotted curves is the effect of accounting for the role of the financial system. See text for expanded interpretation and discussion.*