Driving sustainability transitions through financial tipping points

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Abstract

Achieving a net-zero carbon economy requires significant structural changes in the financial system, driving a substantial shift in investment towards low-carbon assets. This transformation of finance is necessary beyond the objective of climate stabilisation, but is more broadly required to foster sustainably thriving economies. In this paper, we offer a critical discussion of the positive tipping points that can be activated in the financial system to drive a fast, sustainable transition. Indeed, the identification and activation of critical and positive tipping points can lead to the amplification of sustainable investments and foster transformative changes in the practices of the financial sector. Through the alignment of expectations, steering of herding behaviour, mobilisation of public finance, reduction of capital costs, attainment of low-carbon investment thresholds in developing nations, and implementation of robust financial regulations and policies, the financial system can assume a central role in re-orienting economies onto a net-zero and sustainable course. Taken together, such mechanisms highlight the positive tipping points that can be triggered within sustainable finance and emphasise the necessity of policy interventions to activate and capitalise on these dynamics.

Keywords

Sustainable finance, tipping point, expectations alignment, feedback loop, path-dependency, investment threshold and dynamics, herding behaviour, financial regulation and policies

1. Introduction

Scientific consensus regarding the need to reduce increasing resource demands is unequivocal (IPCC 2022, Richardson et al 2023), as humanity faces a confluence of urgent environmental challenges, including climate destabilisation and biodiversity collapse. In the face of this unprecedented situation, the financial system is called upon to play its part in shifting the economy back towards a 'safe operating space' (Rockström et al 2009). This necessitates a rapid shift from financing the 'undesirable' (i.e. the 'dirty', the 'harmful') to financing the 'desirable' (i.e. the 'sustainable', the 'green'). However, the primary function of the financial system, as widely accepted within most advanced (market-)economies, is to maximise financial risk-adjusted returns. Finance is agnostic with respect to the greenhouse gas emissions of its activities, or whether they promote or harm biodiversity. The effective implementation of finance in a sustainable manner, or 'sustainable finance', is thus not assured. Indeed, the current economic paradigm to which finance predominantly adheres is based on ever-rising demand, short-term profitability, inadequate environmental policy and unclear industrial priorities at both national and international levels. In this context, perpetuating historical patterns remains the preferred approach for the financial sector to ensure profitability, and as such it fails to fulfil its transformative role (Ameli et al. 2019, Christophers 2022). Driven by backward-looking, climate- and nature-blind indicators, and ignoring the complexity and systemic impacts of their investments on the environment (Chenet et al. 2021, Crona et al. 2021), financial actors continue to allocate massive amounts of capital to environmentally damaging industries, such as fossil fuel assets and deforestation. This practice consolidates carbon lock-ins and contributes to long-term biodiversity decline (FTM 2023, Ruzzenenti et al 2023, Svartzman et al 2021, Kedward and Ryan-Collins 2022). Ironically, by doing so, the financial sector is driving the accumulation of environment-related financial risks to which, by its own admission, it is now dangerously exposed (Chenet 2024).

Our paper discusses a number of mechanisms that may push the financial system towards positive tipping points, potentially triggering transformative change across the real economy by influencing the volume of financial flows and the associated costs. Tipping points describe critical thresholds in a complex system that, if crossed, activate self-perpetuating processes of change that drive the system into a qualitatively different state (Lenton 2020). Here, the complex system under examination is the financial system, broadly defined as the set of banking and non-banking financial institutions, regulatory bodies and investors, along with the market and non-market relationships they share among themselves and with the real economy. Especially after the Global Financial Crisis (2008-2009), the financial system has been increasingly understood as a complex system (e.g. Farmer and Foley 2009; Dosi and Roventini, 2019), that is, a system composed of heterogeneous interacting entities characterised by varied emergent properties at the macro level which are shaped by the structure and dynamics of these interactions. The architecture of the financial system determines the direction and allocation of financial flows to different economic actors and sectors, thus propelling activities in favoured segments of the economy with substantial financial capital, while constraining activities in less favoured areas. Governments, central banks and regulatory authorities through the exercise of their powers to frame policy and regulations, can alter the structure and the dynamics of the financial system. This provides the opportunity to activate positive tipping points leading to a structural transformation of the real economy.

Here, we focus our analysis on positive tipping points, which describe how social, political, economic or technological systems can shift rapidly into new system states (Tabara et al. 2018), that are less harmful, or even offer solutions to the challenge of climate change. While the examples discussed herein predominantly focus on climate finance, similar reasoning and principles can be applied to broader sustainability issues, such as biodiversity. Indeed, the financial sector is currently modelling its approach to biodiversity finance on climate finance principles developed over the past decade (Chenet 2023). Transformation of the financial system is not the singular, definitive solution capable of addressing all environmental challenges. Finance functions merely as a tool, affecting change through its interactions with the real economy, and should be viewed as part of a broader strategy incorporating, for example, industrial policy, transition planning, social justice, and changes in consumption habits. This holistic approach is crucial to ensure a long-term equilibrium of humanity within planetary boundaries. Our objective is to leverage the theoretical and empirical aspects of the financial system, as it is or as it could be reimagined, to explore how it could more effectively address the systemic challenges we are facing. Rather than presenting a prescriptive solution, our efforts represent an initial inventory of potential tools. We thus try to provide a broad overview of how tipping points may facilitate the transition to sustainable finance, while recognising the composite nature of the financial system. Some dynamics may hold relevance across diverse contexts globally, others are more suitable for specific sectors, regions or stakeholders.

The next sections are organised as follows. Section 2 discusses the role of the financial system with respect to the problem of sustainability and climate change in particular; section 3 provides a critical overview of the positive tipping points that may be activated in the financial system and offers a (non-exhaustive) review of the available empirical and modelling evidence; finally, section 4 concludes the paper and summarises the key points.

2. The financial system in the face of environmental challenges

In the 2000s, the financial sector was largely absent from the key discussions on climate change and the environment. Banks' action on climate change was limited to reporting on the efficiency of their light bulbs and reducing business trips, with no mention of the detrimental consequences of their increasing lending to fossil fuels companies.[1] An important milestone was the 2015 Paris Agreement, which explicitly acknowledged the role of finance in addressing climate change through Article 2.1(c) (Zamarioli et al. 2021). Although its full implementation is still pending, it triggered a new institutional regime and narrative related to finance and climate change, highlighting the responsibility of the financial sector to shift the economic pathway in line with climate targets. In the same year, Mark Carney's speech on financial stability and the risks associated with climate change (Carney, 2015) brought the topic of climate-related financial risk to the fore. By emphasising the urgent need for financial institutions to adopt climate risk management and reporting measures 'before it's too late', Carney initiated an important climate move, mainstreaming climate change in discussions of the financial sector's practices and regulations. Fully establishing transparency across the financial system thereby became a prime goal of financial policy, regulation and industry

[1] See e.g. BNP Paribas Annual Report 2005 - https://invest.bnpparibas/en/document/annual-report-2005 [pp. 68-72, 107-113, 330-344]

efforts in the climate finance arena (Ameli et al 2021a). A similar path was recently followed by financial institutions and authorities concerning biodiversity (Chenet 2023, 2024). In some respects, Carney's speech can be seen as an institutional tipping point for sustainable finance that kick-started discussions, voluntary initiatives and, eventually, regulatory mandates that have led to distinct changes in the financial sector's operations and practices.

More recently, the establishment of initiatives such as the private sector-led Glasgow Financial Alliance for Net Zero (GFANZ) and the central banks-led Network for Greening the Financial System (NGFS), have demonstrated the growing commitment of financial institutions, from commercial entities to public authorities, to align themselves with climate targets. GFANZ signatories committed to reaching net-zero carbon emissions by 2050, in a manner that is in line with the +1.5°C target (i.e., with limited temperature overshoot and using existing technologies). This marked the first instance in which financial institutions committed and pledged to align with climate targets.[2] On the financial authorities side, the NGFS created a landmark governance framework to better coordinate and regulate financial institutions in addressing climate change. Given their status and regulatory strength within the financial system, this has provided a strong signal to financial institutions worldwide that a low-carbon transformation of their activities is imminently needed.

This sequence of events can be viewed as the initial catalyst, or accelerator (cf. GTPR2023, Fig.2 p.33), for challenging traditional practices in the financial system, prompting financial actors to embark on a different path in terms of their investment outlays (Farmer et al. 2019). These initial shifts have the potential to cross critical thresholds (i.e. 'tipping points'), where a minor alteration can trigger a larger and systemic change, and where nonlinear feedback effects act as amplifiers of such change (Lenton et al. 2022). By influencing the allocation of capital to different sectors or activities, the financial system has indeed the power to affect the evolution and composition of the real economy, thereby opening the way to the emergence of tipping points across sectors.

In a variety of historical episodes, the financial system has acted as an amplifier of shocks, both positive and negative. This phenomenon is commonly referred to as the 'financial accelerator' (Bernanke et al. 1999; Delli Gatti et al. 2010), which describes how developments in financial markets amplify and propagate the effects of minor changes in the economy. For example, bursts of financial bubbles have triggered uncertainty, instability, contagion among financial actors, and feedback loops that cause ripple effects in the real economy, even though the initial shock was not particularly severe. The Global Financial Crisis of 2008 is a prominent example of such a negative shock. On the other hand, financial accelerators have the potential to amplify positive shocks through, for example, mechanisms which dampen the financial fragility of firms operating in the real economy or enhance the effects of innovation and its diffusion, resulting in positive outcomes in the medium and long run (Lamperti et al. 2021). Similarly, favourable financial conditions can magnify the impact of policies aimed at sustaining aggregate demand, creating significant synergies between prudential, fiscal, and monetary measures.

[2] NB: the efficiency of these initiatives is nevertheless questioned, from the business-as-usual of financing decisions (e.g. Sastry et al 2024) to the current 'ESG backlash' in the US (e.g.'The real impact of the ESG backlash', FT 2024, https://www.ft.com/content/a76c7feb-7fa5-43d6-8e20-b4e4967991e7, 'Insurance industry turmoil over climate alliance exodus', FT 2023, https://www.ft.com/content/1dd66ce1-a720-4c56-96d9-8d47f07f376f).

Finance can also have a more direct impact on the real economy. Following Perez (2003), financial actors and, more prominently, public investors (Mazzucato 2013) play a central role in enabling technological revolutions by actively contributing to the advancement and implementation of innovative processes, technologies and services, extending their involvement beyond simply providing funds. In fact, they often take part in the management of the innovation process, assuming the role of financial entrepreneurs and 'picking winners'. But other mechanisms can also operate concurrently. For instance, once a particular path is established, financial behaviours can lead to a self-reinforcing cycle where an accepted choice gains momentum and becomes increasingly difficult to change (Arthur, 1989). Also, financial markets have a tendency to replicate the economy as it is and resist making potentially costly new decisions. Finance thus has the capacity to both expedite or impede the dissemination of new products and technologies, particularly those of utmost importance for the transition to a low-carbon future.

3. Finance and positive tipping points

3.1 The potential for positive tipping points in sustainable finance

In this section, we outline and critically discuss mechanisms that exhibit the potential to leverage tipping points in the financial system, with a particular reference to investments towards low-carbon assets and technologies.

Theoretical and empirical evidence suggests that public finance has a catalytic role for mobilising investments (Mazzucato 2013). Indeed, the ability of public actors (e.g. public investment banks, governmental agencies) to take on risk induces private investors to follow. This is not only due to the substantial amount of funding provided by public actors, but also because of the quality of financing they offer. Public financing, with its long-term horizons, favourable repayment conditions and ancillary support, resembles the role of financial entrepreneurs. By underwriting risks associated with low-carbon investments and supporting specific technological trajectories using green subsidies, public finance can mitigate market uncertainty, potentially creating tipping points in the financing of low-carbon projects and assets (Campiglio and Lamperti 2021; Mazzucato and Semieniuk 2018). However, the emergence of positive tipping points cannot be easily guaranteed and needs adequate policy support. For example, a mission-oriented industrial policy shaping the behaviour of financial actors under direct or indirect public control (e.g. public investment banks, development banks, government agencies, large public utilities) can increase the likelihood of positive tipping points in the dynamics of investments and, hence, aggregate production (Dosi et al. 2023).

Expectation alignment on the timing and speed of the transition may also act as a tipping point with the potential to significantly scale up sustainable investment (Campiglio and Lamperti 2021; Campiglio et al. 2023). Uncertainty about the future prospects of low carbon assets coupled with unclear information about the strength of climate policy may delay substantial portfolio rebalancing decisions. In such cases, investors may adopt a more cautious 'wait-and-see' approach, favouring conventional investments whose profitability appears less affected by unclear climate policies. On the contrary, certainty regarding future climate policy schedules through legally-binding climate commitments, carbon budgets and strategic plans, can signal

the long-term trajectory of the economy, inducing a positive correlation between low-carbon asset returns and macroeconomic performance. This alignment of beliefs can coordinate and shift the strategies of long-term institutional investors (e.g. pension funds), which are typically influenced by a wide range of subjective beliefs about asset returns (Broeders and Jansen, 2021). Hence, aligning expectations on the timing and speed of the low-carbon transition could mitigate risk and spur momentum towards sustainable investments. A shift in the investment behaviour of large financial actors may push the financial system past a tipping point resulting in a self-reinforcing cycle in which sustainable investments become increasingly attractive, transforming from mere diversification assets into strategic ones (see Figure 1).

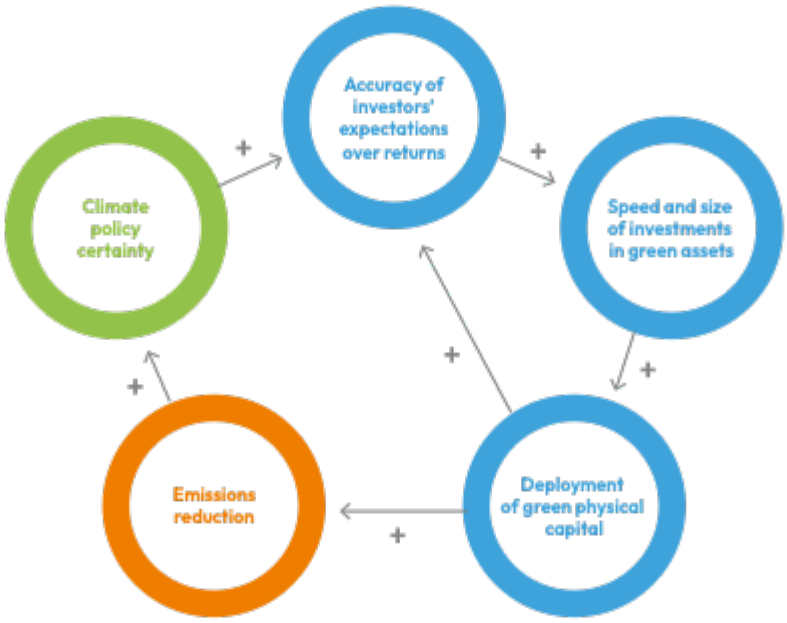

Figure 1: *A positive feedback loop favouring a tipping point in the dynamics of low-carbon investments. The set of self-reinforcing mechanisms and feedback loops occurring in the process between climate policy certainty and deployment of green physical capital. Expectation alignment creates a positive feedback which can be triggered and sustained by certainty in climate policy. The '+' symbol indicates a positive effect (Source: Ameli et al. 2023).*

Tipping points in financial markets can also emerge through herding behaviour, wherein a critical mass adopts a particular trend, ultimately influencing the broader population to follow suit (Bikhchandani and Sharma, 2000). Herding behaviour refers to the tendency of investors to mimic others, especially during periods of uncertainty or when faced with limited information, resulting in the amplification of market movements. In the context of financial tipping points, herding behaviour can have both positive and negative impacts. On the one hand, it can exacerbate market instability and contribute to the formation of speculative bubbles. When investors flock towards certain assets or sectors, it may lead to an unsustainable surge in prices and valuations. However, on the other hand, herding behaviour can also be channelled positively to drive sustainable investments and foster the transition towards a low-carbon economy. For instance, policy action targeted at the global systemically important banks (G-SIB) to ensure financial stability by better managing transition risks in their portfolios, can induce sector-wide portfolio rebalancing away from fossil fuel investments that are mis-aligned

with climate goals and carry stranded asset risks (International Monetary Fund 2023). Similarly, critical mass comes into play when a sufficient number of investors adopt sustainable practices (e.g. if GFANZ were to become a dominant approach) or allocate funds to sustainable investments. This creates a self-reinforcing cycle, attracting more capital and generating increased demand for sustainable products and services. Of course, such a self-reinforcing mechanism should by no means give rise to a 'green bubble'. The significance of herding and critical mass lies in their potential to facilitate the scaling up of sustainable investments. Herding behaviour can rapidly accelerate the adoption of sustainable investments until a critical mass is reached. Once this tipping point is reached, it becomes easier for sustainable investments to attract more funding and support from a widening pool of investors. This positive feedback loop can lead to a transformative shift in the financial landscape, where sustainability becomes the new norm rather than the exception.

These individual tipping points in financial markets signal the existence of sensitive intervention points (SIPs), i.e. identifiable opportunities for deliberate actions that can trigger associated tipping points. SIPs can either be small 'kicks' that trigger positive feedback cycles in a system, or can drive a systemic shift in the inherent dynamics of a system that lead to transformative changes even without external triggers (Sharpe and Lenton 2021; Farmer et al. 2019). Activating an SIP initiates tipping dynamics, causing significant shifts in the market. Policy intervention can serve as the catalyst for such changes directly, by providing the initial 'kick', or indirectly, by shifting the underlying dynamics that bring about the transformation.

Additionally, Farmer at al. (2019) identified two finance-related SIPs. The first involves financial disclosure and falls into the 'kick' type of SIP. Indeed, a change in accounting standards and disclosure guidelines to measure and report climate-related financial risks complemented by policy initiatives such as green taxonomies and sectoral transition plans, could trigger a substantial repricing of fossil assets, such as fossil fuel reserves and securities valuations. Consequently, this would limit the ability of the fossil fuel sector to invest in new fields, thereby reducing committed emissions. Preventing such investments lowers the economic, social, and political costs of transforming the energy industry, as it levels the playing field for renewables, reduces the risk of stranded assets, and enhances the credibility of climate targets. Here, the mechanism at stake relies on market efficiency, a theory where information availability is core to investment decisions and its relevance, in terms of optimal capital allocation. Based on this disclosed information, risk/return expectation will be the prime – if not the sole – guide for financial institutions, which would then contribute to the transition with no need to have any extraneous intention to align their portfolio with such transition goals. Disclosure of environment-related financial risk has been the most prominent mechanism promoted by financial authorities and institutions over the last decade, despite its inherent limits (Ameli et al 2020, 2021b). These concern the extent to which markets can effectively incorporate disclosed financial risk information in asset prices without any long-term guidance concerning an inherently uncertain and evolving low-carbon transition. The progressively more 'interventionist' regulatory propositions, especially in Europe, can be seen as attempts to correct these limits.

The second SIP pertains to technology selection and a targeted 'shift' towards low-carbon investment. Contrary to traditional portfolio theory, diversification of investments can be detrimental, especially when it comes to developing novel and uncertain technologies where spreading resources too thin can hinder significant progress. Instead, rapid progress requires

concentrating resources on specific technologies (Way et al. 2019). For example, solar PV has achieved remarkable progress due to targeted support, becoming cheaper than most alternatives. The next step is to similarly focus on developing technologies that can accelerate the deployment of solar PV, such as energy storage. In essence, inducing a tipping point in this context involves not attempting to invest across a broad range of options with hopes of developing each of them but concentrating efforts on technological complementarities that synergistically support research, development, and actual deployment. Further, identifying these technological complementarities dramatically reduces technological uncertainty, which would amplify the dynamics of technology diffusion even further. In contrast to pure market mechanisms, such choices may be directly or indirectly fostered by public sector interventions, in line with some sustainability transition planning. The objective here is to align financial portfolios with an environmental goal or scenario.

There may however be trade-offs involved between the two SIPs wherein the policies and practices related to disclosure of climate-related financial risks and portfolio realignment may result in lower investments in low-carbon projects due to a higher perception of transition risks. This is possible both in cases of 'bridge' technologies that may have uncertain prospects in the longer term, such as hydrogen-fuelled transport or storage solutions, and innovative low-carbon technologies, such as marine power, whose future cost and deployment trends are highly uncertain. The inherent uncertainty of the energy transition may create higher perception of risks due to indeterminate eventual outcomes, specific technological trajectories or timing of different climate-mitigating actions. Strong policy choices, however, can foster market confidence, despite risks of inefficiency, to create a conducive environment where portfolio realignment is accompanied by higher investment in technologies necessary for a timely energy transition.

3.2 Empirical and modelling evidence of tipping points in sustainable finance

In terms of empirical and modelling evidence, a variety of examples show how the financial system can play a pivotal role in activating tipping points to accelerate the transition to a net-zero carbon economy.

In developing countries, policy support can help to overcome climate investment traps created by the high costs of accessing finance (Ameli et al 2021a). Access to finance, understood as the costs of raising funding for a specific project from different sources, varies significantly across countries. For instance, in some African nations, such as the Democratic Republic of the Congo, Madagascar and Zimbabwe, the cost of capital can soar to 30%, while in developed countries such as Germany and Japan, it can be as low as 3% (Ameli et al 2021a). The high cost of accessing capital is preventing developing countries from decarbonizing their economies. Levelling the finance playing field could thus help poorer nations to steer their economies onto a net-zero course.

While energy system transitions in developing economies require particularly high investment, these parts of the world are also particularly financially constrained. They are characterised domestically by under-developed capital markets and lack of capital stock (Ameli et al 2021a). Furthermore, international finance is restricted due to high sovereign and local currency risks. Projects funded with foreign currency while generating returns in local currencies lead to

volatile economic fundamentals (Ameli et al 2021b, Bilir et al 2019), resulting in restricted access to external funding sources. This leads to a chronic lack of available finance to support low-carbon investments, creating a climate investment trap which occurs when climate-related investments remain chronically insufficient, with dynamics similar to those of the poverty trap (Ameli et al 2021a). A self-reinforcing cycle takes place where high risk perceptions lead to increased capital costs, delaying the transition to cleaner energy systems and carbon emission reductions. Climate change impacts exacerbate the situation (IPCC 2022), causing adverse impacts on production systems, economic output, unemployment, and political stability (see Figure 2).

Policies that reduce capital costs, such as credit guarantee schemes, foreign exchange hedges and political risk insurance can shift risk away from private investors resulting in a lower cost of capital that may act as a tipping point for low-carbon technology deployment and allow developing economies to achieve large sustainable energy capacity and faster emissions reduction. In the case of Africa, reducing the cost of capital by 2050 would allow the continent to reach net-zero emissions approximately 10 years earlier than when reduction is not considered (Ameli et al, 2021).

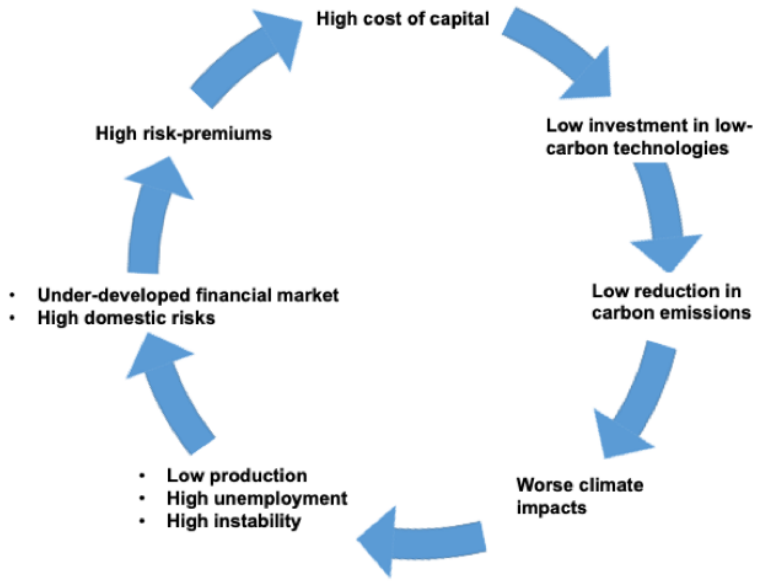

Figure 2: *A climate investment trap. The figure shows the set of self-reinforcing mechanisms and related links occurring in developing economies characterised by high cost of capital. The strength of these links is strongly linked to local conditions implying that the set of self-reinforcing mechanisms could be exacerbated (or less relevant) in some economies. Note that some mechanisms are more relevant at global/regional levels through aggregations across developing countries. For instance, local carbon emissions are not necessarily linked with local climate impacts.*

Additionally, the flow of international capital into renewable projects in developing countries is influenced by path-dependency, creating a tipping point in the scaling up of renewable investments (Rickman et al. 2023). Countries with a track record of renewable investments are more likely to attract future investments leading to positive feedback loops within

renewable energy markets. As countries build a track record in renewables, market confidence grows, bringing down financing costs and attracting further investments in a virtuous cycle (Egli et al 2018). Climate investment thus evolves through the strengthening of historical investment and capital stock, rather than new investment. However, this also results in an 'investment lock-in' across countries as well as income groups, with only a small fraction of countries receiving the majority of investment. Between 2010 and 2019, 76% of private capital and 67% of public funds went to the top eight recipient countries (Rickman et al. 2023).

Evidence of path-dependency thus implies a new mechanism of the 'climate investment trap' whereby historical inequities in financing are locked-in across countries and income groups and perpetuate over time. To escape this investment lock-in, developing countries must mobilise sustained investment to build a renewables track record that creates market confidence and attracts private finance. Indeed, there is a non-linear relationship between the probability of private investment in developing countries and their track record in renewables investment, as measured by installed capacity. Once a significant capacity base of around 1GW (of wind or solar) is installed a tipping point is reached and the probability of private investment increases sharply (Rickman et al. 2023). Crucially, low-income countries (e.g. in Sub-Saharan Africa) fall far below this threshold, highlighting the inefficiency of opening finance channels into poorer nations without sustained investment which can mobilise private finance at scale. Investment decisions by public actors should thus move beyond project-specific inducements to support more holistic renewable roadmaps and unlock developmental co-benefits (Schwerhoff and Sy, 2017). Innovative financial and policy mechanisms, such as transition plans with public funding from multilateral agencies and associated labelled transition financing products, can target the evolution of the sector and build networks of relationships in the financial sector to initiate path-dependent flows from private sources (Ameli et al 2021b) and leverage tipping points in the renewable finance ecosystem.

Inducement effects between investors are another example of tipping points that can be leveraged in sustainable finance. Financing in renewables markets is driven by a heterogeneous set of actors spanning energy, financial, utilities and diversified sectors (Mazzucato and Semieniuk 2018), who invest according to their investment remits, preferences and capacities, as well as technological maturity and the market environment. They collaborate across the development and operational stages of a project based on their risk appetite and expected return, contributing different types of capital to the project in the form of equity and loan investments. Their interaction and relationships drive the market growth and technological maturity of renewable technologies within the energy system resulting in unique emergent characteristics of the renewables sector across countries based on their enabling investment environments.

In solar finance markets, co-investment relationships between different actors are established at different stages of the market's development and evolve with the continued growth of the sector (Kothari et al 2024). Actors exercise influence over their peers by inducing them into the market and leveraging their investments alongside their own. These facets of relationships differ between different actors in the solar sector based on existing co-investments, market position of actors and the alignment of their interests. As markets evolve and different actors enter the market, these processes of influence create tipping points in investment trajectories. In the initial stages of the market development, for instance, investments by government agencies induce investment by international institutions, supporting the initial deployment of

411 the technology. Increasing investments by renewable energy companies similarly influences
412 the actions of state-owned and private utilities. As markets grow, the involvement of
413 institutional investors creates the largest leverage (i.e. the amount of investment attracted)
414 through sizable investments from the private banking sector who are their natural debt partners
415 in renewable projects. The development of this relationship thus creates large flows of
416 investment into solar energy as a result of their investment dynamics.

417 Country context also determines the structure of solar finance markets and the strength of
418 relationships between different actors. The influencing power of different actors differs
419 significantly across countries. For example, in the United States, private bank lending induces
420 investments from a range of energy and diversified sectors, whereas in China, government
421 agencies and state-owned banks are major influencers and in Germany, renewable energy
422 companies and state-owned utilities exert a strong influence (Kothari et al 2024). From a policy
423 standpoint, therefore, it is important to consider the impact of policy instruments on prominent
424 actors in solar financing and the relationships that are driving the markets. Creating incentives
425 for these actors or using the relationships formed by government agencies and state-owned
426 actors effectively, can induce other actors into the markets and trigger non-linear growth of
427 investment, particularly from the private sector.

428 Theoretical modelling also reveals tipping points in the global network of banks which supply
429 debt to the fossil fuel industry (Rickman et al. 2024). A sharp decline in fossil fuel use is
430 necessary to achieve the Paris Agreement target of keeping global temperature rise below
431 1.5°C (Tong et al. 2019) and this will require a corresponding decline in bank lending to the
432 fossil fuel sector (Kirsch et al. 2021). However, mainstream financial theory holds that debt
433 flows to the fossil fuel sector will be resilient to the phase-out of lending by climate-friendly
434 banks, as their capital can simply be substituted by banks with a neutral stance on the climate
435 transition (Ansar et al. 2013). Capital substitution thus poses a challenge to a system-wide
436 decline in fossil fuel lending in an unregulated market. Macroprudential tools[3], such as capital
437 requirements rules, can counteract capital substitution by disincentivizing, or setting a limit, on
438 the amount of fossil fuel assets a banks' can hold, depending on their capital reserves. Models
439 suggest that while fossil fuel debt markets are resilient to the unregulated phase-out of capital,
440 the introduction of carbon-tilted macroprudential regulation can trigger a rapid contraction of
441 fossil fuel debt flows. The first banks to exit the fossil fuel debt market have little impact on
442 debt flows, as their capital is substituted by other banks. However, a sudden transition is
443 observed after a certain number of banks have exited the sector, at which point debt flows
444 sharply contract. The tipping point depends critically on the stringency of regulations; the
445 number of banks that must exit the sector before the tipping point is reached decreases rapidly
446 as regulatory rules are tightened. Moreover, the tipping point is reached sooner if large banks
447 (G-SIBs) move first and coordinate their actions.

448 Suitable macroprudential regulation, such as capital requirements rules, or other policy
449 measures which cap a banks' fossil fuel assets, will deliver a managed decline in fossil fuel
450 lending. On the one hand, overly stringent requirements could precipitate a tipping point too

[3] Macroprudential policy is composed of different tools having the goal of preserving financial stability. This includes making the financial system more resilient to losses and limiting the build-up of vulnerabilities in order to mitigate systemic risk and ensure that financial services continue to be provided effectively to the economy.

early, leading to a disruptive transition in which the failure of fossil fuel companies is too widespread to be managed sustainably. On the other hand, loose requirements resulting in a late, or non-existent, tipping point could delay the emissions reductions necessary to keep Paris temperature targets within reach. Such rules can be developed by formal standard-setting bodies and prudential regulators such as the Basel Committee on Banking Supervision and the Financial Stability Board. At the same time, banks could strategically coordinate their transition plans to increase their collective impact on debt markets through voluntary alliances such as the Net Zero Banking Alliance (NZBA 2021), to which many of the most influential banks in the sector are signatories. Here again, we see the articulation of the two basic mechanisms activatable within the financial system: market-driven risk/return dis/incentives, and purpose-driven alignment strategies.

Finally, the utilisation of policy mixes that incorporate a combination of command-and-control and market-based instruments can be likened to 'kicks' that yield positive outcomes for the transition to a net-zero carbon economy. These could take the form of policy mandates such as progressive emissions reduction targets, environmental and industrial regulation, mandated transition planning, green central banking, green infrastructure requirements and building codes working alongside market-shifting initiatives like carbon pricing, climate-related financial disclosures, green subsidies, risk underwriting mechanisms and green certificates. Recent advancements in modelling have demonstrated that these policy combinations have the potential to initiate a virtuous cycle, driving technological development, reducing the overall need for public investment, and simultaneously stimulating employment and economic growth (Wieners et al. 2023; Lamperti et al. 2020; Lamperti and Roventini 2022; Stern and Stiglitz 2023). Moreover, such positive feedback loops significantly lessen the reliance on carbon taxes by decreasing their intensity. As a result, this enhances their political acceptability and potentially triggers another tipping point.

The importance of these tipping points in the financial system will ultimately be defined by the impact they have on the decarbonisation of different sectors in the economy. A regulatory mandate or a market-based measure that affects only a subset of the financial market, such as commercial banks or publicly-listed companies, or only impacts flows from a specific country or geography (such as EU-wide), could potentially lead to redistribution of high-carbon assets across the financial system rather than their absolute reduction, resulting in limited economy-wide decarbonisation. Broad-based policies are thus needed to influence a sizable portion of markets to pass a tipping point where financial markets are unable to adequately substitute the money leaving high-carbon assets. Further, different financial policies are likely to draw a diverse response from market participants, such as the impact of capital reserve requirements for the banking sector or carbon disclosure requirements for asset managers that might not have a significant impact on other actors like private equity funds. Thus a combination of financial policies will be needed to cover the various investment channels in the financial system. Specific policies will also be needed to spur investments in climate projects by mandating investments in specific green sectors or providing market-based incentives that influence the risk-adjusted returns of these projects. This will ensure that capital flows diverting from high-carbon sectors reach their intended target and lead to decarbonisation of the economy. Similarly, targeted international flows to developing countries will result in an expansion of green sectors in these countries and thereby sustainable development. Further, the interlinkage between financial and other economic systems needs

to be acknowledged. Policy mixes work well because they influence multiple systems and attempt to gain non-linear benefits through reinforcing mechanisms and positive tipping points.

4. Conclusion

As of today, the financial sector is contributing to a projected +3°C global warming scenario by 2100. The financial system itself does not inherently favour any particular climate objectives ex ante. To successfully shift the economy towards a net-zero emission path, it becomes crucial to harness the potential of tipping points in the financial system in order to contribute to this transition in its full capacity, by enabling and accelerating the necessary capital reallocation. These elements can play a pivotal role in redirecting economic activities towards sustainable practices.

Taken together, the mechanisms detailed above highlight examples of the system-wide tipping points' potential within sustainable finance and emphasise the necessity of policy interventions to activate and capitalise on these dynamics. Through the alignment of expectations, promotion of herding behaviour, utilisation of public finance, reduction of capital costs and attainment of low-carbon investment thresholds in developing economies, and implementation of robust financial regulation and policies, the financial system can assume a central role in expediting the shift towards a net-zero carbon economy.

Regulation plays a critical role in driving tipping points within the financial sector and its role has become increasingly prominent in recent years. A climate risk information ecosystem has evolved with standards for climate-related financial data, assessing climate risk impacts, transparency requirements, green taxonomies, green labels for financial products and transition risk management plans (International Monetary Fund 2023). Robust monitoring and supervision by entities like central banks and financial regulators are forcing financial institutions to move faster and more decisively than market signals alone would prompt them to do. In this regard, policy makers and financial authorities hold the potential to take a leading role in steering the financial system towards transformative tipping points, dedicated to financing the transition to a net-zero carbon economy. A just transition needs investments in all parts of the economy and society. This will in-turn require policy combinations incorporating both market-based and structural change instruments to work effectively to deliver opportunities and investment-friendly conditions while avoiding trade-offs between prudential behaviour and a shift in asset allocation by financial institutions to low-carbon activities. As key stakeholders increase their efforts to guide the financial system, leveraging all the available tools and exploring new avenues, they can also create a coordinated momentum with industrial policy makers. In this way, financial and economic policies can be more effectively aligned to support sustainable industries and practices. This collaboration further strengthens the potential to tip the financial system into a new momentum, where the identification of critical intervention points can lead to the amplification of sustainable investments, mitigate risks, and foster transformative changes in the practices of the financial sector.

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