Section 4

Positive tipping points in technology, economy and society

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Section summary

'Negative' tipping points are now so close that urgent action needs to be taken to prevent them. Beneficial, 'positive' tipping points (PTPs) offer hope for accelerating responses to match this urgency. A key task will be to learn how to intervene in socio-behavioural, technological, economic and political systems in ways that enable PTPs to emerge while minimising harms and injustices. Enabling PTPs means, for example, making the desired change the most affordable, attractive, convenient, accessible or morally acceptable option. PTPs occur when the balance of system feedbacks – reinforcing/amplifying versus dampening feedbacks – shifts in favour of reinforcing ones, such as economies of scale, or social contagion. A PTP in one system can trigger one or more PTPs in other systems in a domino or cascade effect, generating widespread societal change.

PTPs are already well underway in wind and solar power generation and in leading battery electric vehicle (BEV) markets. But the supply of technological solutions on its own is unlikely to be sufficient to meet decarbonisation targets. It is also important to trigger PTPs in the demand for energy and transport services and food – for example, by making public transport the cheapest, most convenient option. Coordinated action between supply and demand amplifies the impact of each. Accelerating change in food systems also has important 'positive cascading' implications for natural ecosystems, accelerating nature recovery and restoring natural carbon sinks. Other changes – in behavioural norms, values and practices; in political institutions, policy priorities, and public pressure; in global financial systems and international funding mechanisms; and in digital and information systems – are also vitally important for delivering the necessary speed and scale of systemic change.

In certain systems we can detect the signals, or 'early opportunity indicators' (EOIs), of approaching tipping points. Further development of EOI research could help decision makers – from politicians to investors – harness the power of the PTP approach.

Key messages

- Transformative and just positive tipping points can emerge with the right enabling conditions, feedbacks and triggers.
- Climate solutions focusing on fundamental shifts in behaviours, values and institutions are as important as those that focus on technologies, materials and markets.
- An avoid-shift-improve logic which rethinks our activities – whether they can be omitted, changed or undertaken more efficiently – can be used in many sectors to design interventions to manage holistic structural change.

Recommendations

- Positive tipping point theory, methods and applications will require a comprehensive, systematic and transdisciplinary programme of research and development.
- Decision makers need a systems-thinking approach and a coordinated strategy that encompasses all economic sectors, all departments of government, civil society (including public consultation), and both supply-side and demand-side interventions.
- A systems-thinking approach understands that the most effective way to catalyse global action may be via small-group coalitions. For example, a positive tipping point in green hydrogen could be achieved if the US, EU and India implemented blending mandates for green ammonia in fertiliser manufacturing.

Section 4.1.1: Summary table

Sector-system	PTP opportunity	Emissions share	Key enabling conditions	Key reinforcing feedbacks
Energy & Power	**Shift:** Solar PV/wind + storage	26%	• Levelised cost of electricity of new solar/wind + battery storage is less than that of new coal/gas power • Sufficient transmission and distribution infrastructure	• Economies of scale • Learning effects • Social contagion for domestic installation • Technological reinforcement for domestic battery installation (with flexi-tariffs)
	Shift: Domestic heat pumps	6%	• Well insulated housing stock • Competitive on installation cost and time with gas or equivalent boiler (including subsidy) • Running costs competitive with gas	• Economies of scale • Learning effects • Social contagion for domestic installation • Technological reinforcement i.e. when integrated with home solar and battery system
	Shift: Steel production: green hydrogen DRI	7%	• Cost per ton of production lower than steel from fossil-based productionInstitutional commitment by large manufacturers • Enabling policy and market demand for low carbon steel	• Economies of scale • Learning by doing • Technological reinforcement • Path-dependency of investment decision-making
Transport & mobility	**Shift:** Battery electric vehicles	9%	• BEVs cheaper at point of purchase than ICE vehicles (including policy support) • Sufficient charging infrastructure • BEV performance seen as competitive with ICEV's by consumers • Policies that increase BEV desirability including waved parking fees, access to fast lanes, and entry to air quality zones)	• Economies of scale • Learning by doing • Social contagion and network effects
	Avoid: Enhanced active mobility	Up to 9% (or more)	• Enabling infrastructure (e.g. safe streets, compact city development, hire/rental schemes) and policy design (e.g. carbon pricing, subsidy, vehicle restriction schemes) • Norm change	• Social contagion and network effects
	Shift: Enhanced heavy capacity public transport networks	Emissions, air quality and economic (SDG) benefits (unquantified)	• Investment • Enabling policy	• Demonstration effect • Economic development feedbacks of infrastructure access
	Shift: Heavy duty freight - Battery electric trucks	3%	• Total cost of ownership lower than ICE trucks • Sufficient high-speed charging infrastructure • Performance equivalent or better than ICE trucks	• Economies of scale in battery production • Charging infrastructure network effects • Asset sharing via digital platforms to drive efficiency improvements
	Shift: Shipping: green ammonia	3%	• Green ammonia fuel cost less than fossil-based shipping fuel • Effective regulation and incentives for shipping sector	• Economies of scale • Learning by doing in green ammonia sector
	Shift: Aviation: power-to-liquid fuels	2%	• Power to liquid fuel costs less than fossil-based jet fuel for long-haul flights	• Learning by doing • Economies of scale in PtL fuel production
Food & Agriculture	**Avoid:** food loss and waste	8%	• Effective policy and regulation • Buy-in from supermarkets • Shifting norms and behaviours	• Learning by doing • Social contagion • Technological reinforcement via digital platform evolution
	Shift: more plant-based diets	Up to 12%	• Shifting norms and behaviours, e.g. via public procurement, information • Improved alternatives to animal products, which are competitive on cost with animal products	• Social contagion, demonstration effects, network effects • Economies of scale and learning by doing in production of alternatives to animal products

Section 4.1.1: Summary table

	Shift: to regenerative agriculture	Up to 4% via CDR, plus additional emission reductions and ecological benefits	• Subsidy or other incentives that support farmers to transition and diversify business models, including carbon markets • Regenerative practices have lower input costs or higher productivity than conventional • Information and education on regenerative practices is accessible	• Information cascades • Network effects • Social-ecological feedbacks
	Shift: Fertiliser	2%	• Green ammonia costs less per ton than grey ammonia for N-based fertilisers	• Economies of scale and learning by doing in electrolyser development
Social & behavioural systems	**Shift:** Anti fossil fuel norms; **Avoid:** sufficiency norms	n/a	• Free social spaces for social innovation • Supportive networks legitimising new norms • Policy intervention (e.g., remove fossil fuel subsidies) and public investment • Philanthropic funders as incubators, connectors and mobilisers of new norms	• Increasing acceptability of new social norms • Complex contagion seeded by climate activism • Facilitated routes for new information to flow • De-escalation of polarising narratives • Opportunities to experience positive exemplars
Political systems	**Avoid:** Ecocide Law	n/a	• Political coalition-building and public engagement • Policy coalition-building and international diplomacy	• Increasing awareness and support for policy • International social contagion • Ostracism of non-cooperators
	International climate clubs	n/a	• Establishment of new climate negotiation norms • New international institutionsInvolvement of business, finance and civil society	• Increasing adoption • Increasing success in catalysing global action • Coordination and network effects
Legal systems	Climate change litigation	n/a	• Public perception/acceptability • Supportive media coverage • Supportive changes in climate-relevant laws • New legal institutions., eg., commission for future generations	• Successful litigations, network effects • Increasing international standing of human rights-based grounds for legal action • International standing of adaptation- and financial compensation-based grounds for legal action
Financial systems	**Shift:** Accelerating the green transition	Potential to interact with multiple high-emitting sectors	• Expectation alignment between policy and investment communities (e.g. through public finance initiatives, policy certainty) • Low-carbon investment is seen as a strategic asset rather than a diversification asset (e.g. less risky than carbon emitting investment options) • Strategic policy intervention (e.g. signalling focus on a specific solution)	• Feedbacks between public and private finance • Network effects among financial institutions • Learning by doing (e.g. increasing experience of returns from low-carbon investment) • Investment → technological development → stimulating employment and technological growth
	Shift: Accelerating renewables investment in the Global South		• Investments in Global South seen as no more risky than equivalent in the Global North (e.g. via credit guarantee (schemes) • Capacity base of around 1GW wind or solar installation	• Demonstration effect → countries with track record of renewable investments are more successful at attracting new investment due to investor confidence • Network effects - crowding in investment • Mobilising domestic capital initiates economic development feedbacks
	Shift: De-financing fossil fuels		• Stringent capital requirement rules • Risk of exposure to stranded assets	• Network effects • Financial feedbacks
Cascades	Multi-sector tipping points harnessing **Avoid-Shift-Improve**		• Cross-government and cross-sector coordination of climate policy • Super-leverage interventions to ensure favourable costs, accessibility, desirability and performance across target systems/sectors	• Co-evolution of coupled systems • Social contagion • Learning by doing • Economies of scale • Network effects

Chapter 4.1 Positive tipping points in technology, economy and society

Introduction

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Previous sections of this report examine 'negative' Earth system tipping points (ESTPs) (Section 1), their impacts on human society, which could also trigger 'negative' social tipping points (Section 2), and governance options for avoiding or adapting to these risks (Section 3). This section investigates the opportunities for positive social tipping points, which we shorten to positive tipping points (PTPs). A PTP can be defined as a change in a system or subsystem, which becomes self-reinforcing beyond a critical threshold, and which leads to substantial, frequently abrupt and often irreversible impacts that are predominantly beneficial (Armstrong McKay et al., 2022; Milkoreit et al., 2018). As discussed briefly in Box 4.1.1 and at greater depth in Chapter 4.6, what is considered normatively 'positive' or beneficial, and by whom, is highly debatable. In principle, tipping points may be considered positive either: a) where they reduce the drivers of 'negative' Earth system impacts such as greenhouse gas emissions or deforestation, for example in a rapid shift to renewable energy or alternative food proteins (Meldrum et al., 2023); or b) where they improve the social foundations of sustainability (Rockström et al., 2023; Gupta et al., 2023; Raworth, 2017; Tàbara, 2023).

Box 4.1.1: What do you mean, 'positive' tipping points?

It's easy to understand why climate tipping points are described as normatively 'negative' (harmful, undesirable). They risk destabilising the Earth system on which all life depends. The link between rising temperatures and negative consequences are becoming ever more apparent in the form of wildfires, flooding, storm damage, crop failure, famine, forced migration and other harms. But what about 'positive' tipping points (PTPs)? What are they, for whom are they positive, and who has the power to decide what is 'positive'?

PTPs are a relatively new approach to accelerating the transformation to a sustainable, post-carbon society. They are 'positive' because they aim to prevent the 'negative' impacts of global heating and ESTPs. But PTPs go beyond ESTPs and the prevention of harm. They also refer to those human systems that we (the international community of nations) are actively encouraging to tip, not prevent from tipping, in cases where this would (to the best of our knowledge and care) increase the likelihood of achieving the just social foundations of sustainability – the Sustainable Development Goals (SDGs). A safe Earth system and a just society are both essential for a sustainable future.

However, not all changes associated with societal transformations are universally seen as 'positive'. People working in the fossil fuel and related industries fear the loss of their livelihoods and communities. Pollution, habitat destruction and poor working conditions in the expansion of cobalt and lithium mining (battery components for the new renewable energy economy) create problems as well as opportunities for a different set of communities. Many people, even while being broadly in favour of climate action, are wary of policies that might create additional costs or restrict their freedoms. And some suspect that the new economy isn't going to look much different to the old one in terms of inequities of power, democracy and resources. Forward-thinking governments and firms are developing 'just transition' plans to try to minimise some of these fears and injustices; others maximise and exploit them in the hope of delaying climate action.

Many of us, as individuals and as representatives of organisations, sometimes face difficult decisions and trade-offs as we try to weigh harms against benefits on imaginary scales of justice. Land designated for nature restoration might otherwise be used to grow food. Finance for mitigating technologies may leave less available for adaptation, or for loss and damage. These scales are already weighted heavily on one side by the need to prevent potentially catastrophic levels of harm and injustice that would result from triggering climate tipping points. If we fail to stabilise the climate in time, the SDGs could quickly become impossible. But should ESTPs be prevented at any cost? On the other side of the scales, there may be certain moral or religious principles, minimum standards of human dignity, or duties of care, that we refuse to set aside, whatever the risks. These issues are explored further in Chapter 4.6.

'Positive' and 'negative' are clearly value judgements. However, the moral force in our use of these descriptors is based on the science of Earth system boundaries and tipping points and the ethics of social justice. Almost all people, regardless of values and other differences, believe that human flourishing is preferable to human suffering and share a common interest in securing a safe and just world.

It is easy to understand why there has been such an explosion of interest in the concept of PTPs in recent years (Tàbara et al., 2018). Faced with a polycrisis of multiple, interconnected, and potentially existential, threats, they offer hope of neutralising or mitigating these threats and of creating a safer, healthier and more sustainable world for present and future generations.

PTPs have already been crossed in sociotechnical systems in the uptake of solar and wind power, which are now doubling capacity every three and a half years (IEA et al., 2023; Nijsse et al., 2023). Sales of battery electric passenger vehicles have also crossed PTPs in leading markets such as Norway, and are fast approaching them in the rest of Europe, the US and China (Meldrum et al., 2023). Forward-thinking firms and individuals are exploiting these opportunities, often with the help of governments who alter the parameters – using incentives, direct investments, mandates, behavioural 'nudges', and so on – within which decisions are made. The evidence for PTPs in other human systems is less well established due to a lack of appropriate data, accepted definitions, assessment methods and case studies.

The increased interest has led to some overuse and misuse of the term (Milkoreit, 2023) and, inevitably, to contested definitions and meanings about what should be considered a normatively 'positive' outcome. All such claims rely on subjective judgement. There are also important ethical issues and the possibility of unintended negative consequences to be considered, as PTPs create 'losers' as well as 'winners', and costs as well as benefits (Pereira et al., 2023). These issues are explored further in Chapter 4.6.

The growing risks of ESTPs and more than 30 years of inadequate climate action mean that we don't have time for a 'business as usual' mentality or for the opportunity-driven, largely unforeseen, societal transformations of the past. (Stoddard et al., 2021; Meadowcroft, 2016; Scoones et al., 2015; Geels, 2011). **We need to move many times faster**, in the context of a "rapidly closing window of opportunity to secure a liveable and sustainable future for all" (IPCC, 2023, p. 24; Sharpe, 2023). Human civilisation will fundamentally change in the coming decades. The only question is, will that change be collectively chosen *by humanity* in ways that maximise our wellbeing? Or will it be chosen *for us,* with potentially catastrophic consequences, if we continue to ignore biophysical limits and the risks of ESTPs? It is within our collective abilities to deliver a prosperous, climate-resilient future for all. But we require different priorities and strategies to those on which we previously relied. Most importantly, we need a systems-thinking approach to rapidly accelerate towards PTPs. This means:

- Simultaneously addressing social-behavioural, technological, economic and political domains (Stadelmann-Steffen et al., 2021), and looking at **demand-side solutions** such as changing behaviours, norms, lifestyles and provisioning systems related to consumption (Creutzig et al., 2022; Akenji et al., 2021), alongside **supply-side solutions** such as achieving cost parity for renewables (Meldrum et al., 2023).
- Focusing on more fundamental interventions that connect individuals and systems together and lead to systemic change of underlying socioeconomic structures – in parallel with the easier, lower-cost, 'low-hanging fruit' (Mealy et al., 2023; Newell et al., 2021; Chan et al., 2020; Abson et al., 2017). Examples might include: a revenue-neutral carbon fee and dividend scheme (Boyce, 2019); universal basic services as part of a social guarantee or 'green jobs' guarantee (Akenji et al., 2021).
- Creating synergies between human (social) capital and natural capital (Tàbara, 2023); measuring progress both in terms of reductions in negative tipping point stressors (e.g. greenhouse gas emissions, deforestation, land/soil degradation) and in terms of increases in positive social indicators such as health, food security, education, gender and socioeconomic equality (Rammelt et al., 2023).
- Understanding that human systems are embedded within the Earth system (Figure 4.2.1). The safe operating limits of the Earth system, within which human societies have flourished for millennia, are governed by natural laws (Rockström et al., 2023; Dixson-Declève et al., 2022). Humans are immensely capable problem-solvers, but what we cannot do is adjust these laws for our political or economic convenience.

Systemic change requires us to reimagine how we eat, move, work, consume, invest, live and view the world (Tàbara and Chabay, 2013). It also requires practical changes in how we manage our lands and oceans, raise and spend public money, phase in/out affected industries and train/retrain workforces and redesign cities, energy systems and transport networks. Huge decisions need to be made about the kind of world we want to live in. They must be addressed with a clear understanding of the real risks we face, as well as the opportunities. Civil society, local communities, policymakers and businesses need to be at the heart of co-designing this better future and able to trust each other to deliver a just transition (Devine-Wright et al., 2022; Laybourn-Langton et al., 2021). Politicians need the support of a public mandate and a majority political coalition to enact policy changes (Eder et al., 2023; Willis, 2020).

PTPs therefore involve **complex interconnections and opportunities for systemic change** across multiple domains, sectors, disciplines and countries/jurisdictions. This section aims to highlight some of these interconnections and opportunities in contexts that will help decision makers navigate a responsible and evidence-based path through the complexities, using real-world examples and case studies.

Chapter 4.2 presents a conceptual framework for understanding and acting on PTP opportunities, according to the latest research. Chapter 4.3 demonstrates the usefulness of this framework by applying it to the most carbon-intensive sectors of energy (4.3.1), transport and mobility (4.3.2), and food systems (4.3.3). Previous studies have investigated the rapid innovation and diffusion of technologies in these systems (Meldrum et al., 2023). We build on this work and introduce a demand-side perspective. Chapter 4.4 identifies cross-cutting enablers of PTPs that may be applied to many kinds of human systems: socio-behavioural change (4.4.1); politics (4.4.2); finance (4.4.3), digitalisation (4.4.4) and early opportunity indicators (4.4.5). Chapter 4.5 investigates positive tipping cascades. In previous sections of the report, tipping cascades referred to processes whereby one negative tipping point triggers at least one other negative tipping point, potentially leading to a large overall deterioration across multiple systems. We adapt this concept for PTPs and, again, building on previous studies, we examine the potential for using powerful interventions at specific times and places – so-called 'super-leverage points' (Meldrum et al., 2023) – that are capable of catalysing tipping cascades across multiple systems and domains. Finally, Chapter 4.6 considers important issues of risks, equity and justice in the governance of PTPs, with particular attention paid to the potential for PTPs to create 'losers' as well as 'winners', and to bring a degree of reflexivity and inclusivity with respect to marginalised voices.

Throughout, we give diverse examples from different regions, highlighting the need for differentiated solutions in each case; these are summarised in Table 4.1.1. Some technological and behavioural solutions might be more universal than others, while organisational solutions require context-specific knowledge and tailored actions. The specific scales, levels, sectors or domains in which positive tipping occurs is also addressed. We outline where opportunities to positively intervene exist. And we assess, where possible, the impediments and uncertainties involved. Our assessments are based on empirical insights and modelling studies.

When aiming to accelerate beneficial change, the **avoid-shift-improve framework** (Creutzig et al., 2022) is helpful in prioritising action. Each of the three types of actions can reinforce the others by amplifying their effects. *Avoid* aims to eliminate harmful activities or products by reducing production/consumption or by redesigning services; *shift* means switching to cleaner or more efficient alternatives; *improve* means enhancing the performance or efficiency of the same activity or product. We use the *avoid-shift-improve* framework throughout this section to describe and prioritise PTP interventions.

Chapter 4.2 Understanding and acting on positive tipping points

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Summary

The human systems and enablers of positive tipping points (PTPs) span multiple domains of technology, politics, economy and social behaviour. Many key features of Earth system tipping points (ESTPs) also apply to PTPs, including the presence of reinforcing and dampening feedbacks, nonlinear change, cascade effects, resilience, and path dependence. The primary differences with PTPs (as opposed to Earth system tipping points ESTPs) are intention, agency and desired outcomes. The intention of PTPs is to promote (not prevent, as in ESTPs) tipping and system transformation. Agency is focused on interventions that maximise the potential for tipping to occur. Desired outcomes are systems-compatible with a safe and just world. To encourage desired outcomes, agents can intervene in three ways: 1) they can create the enabling conditions for a tipping point; 2) they can enhance the reinforcing feedbacks that drive change, and/or neutralise the dampening feedbacks that resist change; and 3) they can attempt to trigger positive tipping points. PTP system dynamics typically involve three phases of enabling, accelerating and then stabilising change. Once a tipping point has been crossed, a system enters an accelerating phase of nonlinear change dominated by reinforcing feedbacks, before stabilising again in a qualitatively different state. Other, undesired outcomes are also possible, including 'shallower', less sustainable outcomes, and unintended consequences. Tipping cascades can occur across multiple sectors and domains, as one tipping point triggers another, and then another, potentially leading to widespread societal change.

Key messages

- PTPs don't just happen, they need to be actively enabled by stimulating innovation, shaping markets, regulating business and educating and mobilising the public.
- 'Positive' is a value judgement.
- Rapid decarbonisation may involve losers as well as winners.

Recommendations

- PTPs in solar and wind energy have taken several decades to emerge. Government, business and civil society all need to play a more active part in accelerating progress across all sectors and domains.
- PTP theory and methods require a comprehensive, systematic and transdisciplinary programme of research and development.
- Some PTPs, for example those in sociotechnical systems that depend on achieving price parity, are easier to define and predict than others. Decision makers need reliable information and frameworks to assess the potential for, and proximity of, PTP opportunities to beneficially transform systems.

4.2.1 Introduction

Before examining case studies and cross-cutting themes, we present a framework for helping to conceptualise the PTP approach and how to intervene in complex systems in ways that encourage tipping points to emerge.

4.2.1.1 Similarities between ESTPs and PTPs

Any sufficiently complex adaptive system, whether it is based on geophysical, ecological, or human elements, can exhibit a tipping point that leads to transformative change (Lenton et al., 2022). For this reason, many of the same terms and concepts used to study normatively 'negative' tipping points in the Earth and social system can be adapted for normatively 'positive' tipping points in human systems. The prime example is the tipping point concept itself – **a critical threshold at which an additional input into a system triggers a disproportionately large, often abrupt and irreversible change, which leads to a qualitatively different system state** (Lenton, 2008; Milkoreit, 2018). Both normatively 'negative' and 'positive' tipping point systems also have the following in common:

- Stable states that are resistant to change.
- Internal, reinforcing (positive) feedbacks that speed up change, and dampening (negative) feedbacks that slow down change (Lenton et al., 2022). These are **mathematically** positive or negative feedbacks, not to be confused with **normatively** positive or negative tipping points.
- The potential for tipping cascades, whereby the tipping of one system triggers the tipping of at least one other system, which can start a domino effect of change across multiple systems (Lenton, 2020).
- A loss of resilience or stability when approaching a tipping point. For some human (social) systems this may manifest as critical slowing down (CSD) – the time taken to recover from a shock/ disturbance. CSD can be detected as early warning signals (EWS) for climate tipping points, or as **early opportunity indicators** (EOI) for PTPs.
- Path dependence, in which past states or events constrain future states or events.

4.2.1.2 Differences between ESTPs and PTPs

One obvious difference is that PTPs usually involve intentional change. The kind of beneficial change we are interested in – "collective, intentional transformation towards global sustainability" (Lenton et al., 2022, p. 2) – requires purposeful human agents, either acting alone or organised into various networks, who attempt to induce (and some who try to prevent) these tipping points (Winkelmann et al., 2022). This section therefore introduces some new terms that address the intentionality that is central to operationalising PTPs – terms such as **enabling conditions** (Lenton et al., 2022), and **strategic interventions**. As stated in 4.2.3.4, this focus on intentionality and agency does not negate the possibility of unintended PTPs or triggers.

Another difference, compared to tipping points in the Earth system, is that human systems span very different domains, which we categorise into socio-behavioural, technological, economic and political domains (Bernstein and Hoffmann, 2018) (Figure 4.2.1). The socio-behavioural domain covers changes in social norms, lifestyles, knowledge, values and cultures. The technological domain includes innovation, research and development, adaptation, coordination, and automation of technology. The economic domain includes changes in finance, markets, labour and inequality. The political domain covers changes in the law, politics, policy, institutions and governance. The domains, systems and subsystems of human societies are constantly in flux. They interact with each other and with the Earth system in highly complex ways that can be difficult to predict or steer. PTPs in human systems also manifest at different spatial and temporal scales to tipping points in the Earth system, as illustrated in Figure 4.2.1.

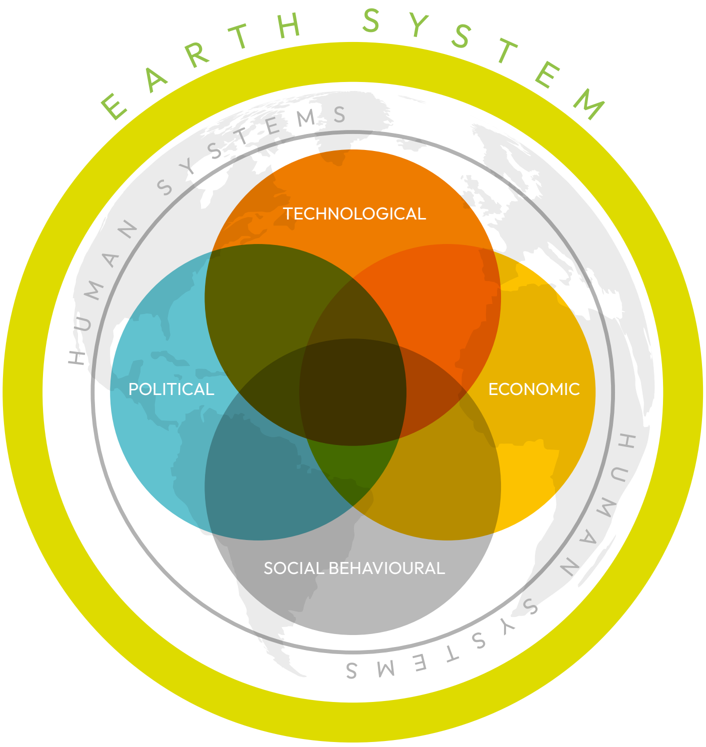

Figure 4.2.1: PTP domains. Human systems – social-behavioural, technological, economic and political – are interconnected. Human systems are also embedded within the Earth system, which means they are subject to their biophysical capacities and tipping points (Stadelmann-Steffen et al., 2021; Rockström et al., 2023).

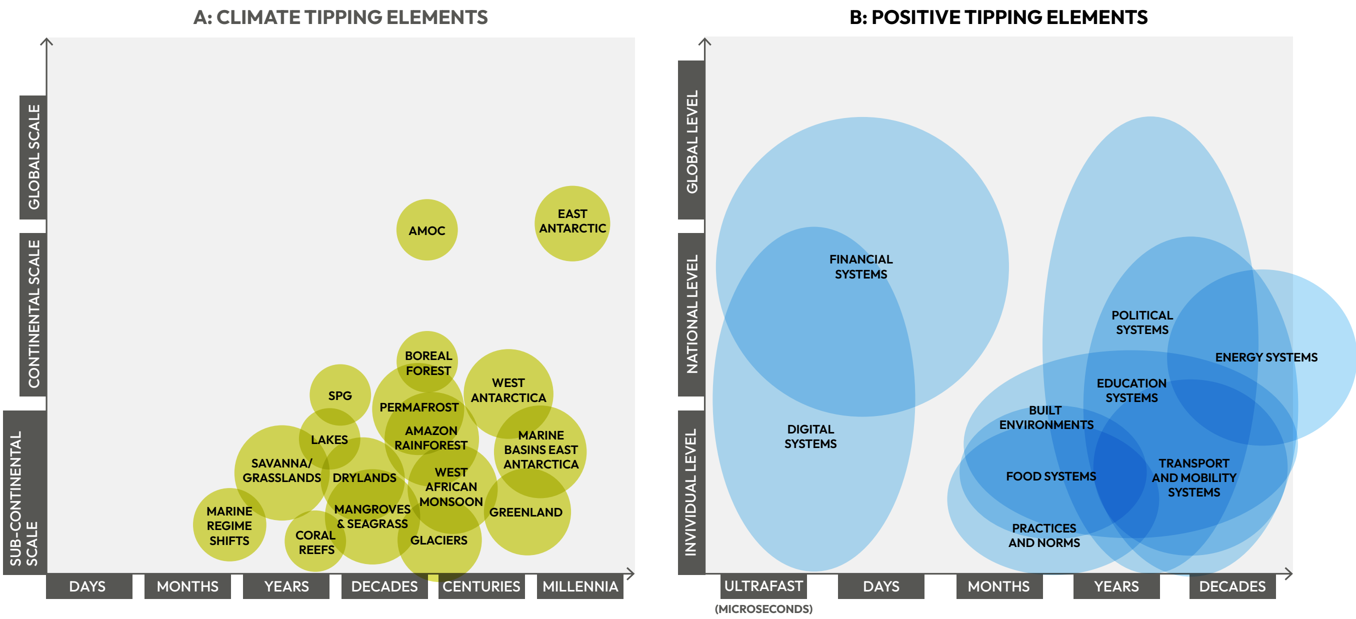

Figure 4.2.2: Typical spatial and temporal scales to illustrate climate and positive tipping elements (adapted from Winkelmann et al., 2022).

Human systems and their tipping points are also, in some ways, more difficult to define and measure than those of the Earth system (Winkelmann et al., 2022; Stadelmann-Steffen et al., 2021). Investigations of ESTPs have built strong empirical foundations based on natural laws, and on data on prior system states going back millions of years (palaeoclimatology). Quantitative units of measurement similar to those used for ESTPs are sometimes used to identify PTPs in technology and economics. But it is more difficult, and contentious, to assert tipping points for other, less-quantifiable systems concerned with change in human behaviours, practices, values and political systems. It is often not possible to identify a single parameter, mechanism or point that triggers tipping in human (social) systems, but rather multiple tipping dynamics that together trigger rapid and fundamental system change (Stadelmann-Steffen et al., 2021). In many cases, the study of tipping points in human systems has tended to rely on literature synthesis, case studies and expert elicitation to determine:

- **Historical precedents** – for example the shift from fossil fuels to renewables in electricity generation (4.3.1), or the Green Revolution (4.3.3).
- The key **characteristics** of the system.
- **Boundaries that distinguish** PTPs from other more established theories of societal change (Milkoreit, 2022). See Box 2.2.1 below.

Box 2.2.1 Positive tipping points for sustainability are characterised by:

- A transformative change in the human components of linked social-ecological systems.
- Nonlinear, rapid change.
- Reinforcing feedback as the change mechanism.
- Limited reversibility.
- Desirability.
- Human agency.
- The intention to support decarbonisation and sustainability.

4.2.1.3 Not all systems have tipping points

PTP researchers and practitioners need to acknowledge that this is a very recent field of study that has yet to devise a formal, empirical way of distinguishing a system that is possible or likely to tip from one that isn't. Incorrectly asserting a PTP could lead to false optimism and damage the credibility of the PTP approach. It could also lead to wasted effort, resources and time trying to induce PTPs in a real-world system that is either incapable or highly unlikely to tip within a useful timeframe.

Sectors that have very high capital costs and very low replacement rates, sectors in which there are no obvious, strong, reinforcing feedbacks to drive change, or sectors in which there are strong dampening feedbacks to prevent change, may be poor candidates for PTP intervention. Hard-to-abate industries such as steel, chemicals and cement, and avoiding land use conversion (e.g. deforestation) are examples of sectors in which there is low confidence that PTPs may occur (Meldrum et al., 2023). We should expect powerful incumbents to strongly resist (i.e. dampening feedbacks) any intervention that attempts to destabilise existing systems/regimes (Kohler et al., 2019). It is therefore critical to identify and assess the relative strengths of reinforcing versus dampening feedback loops before asserting a potential tipping point. Assessing the **relative strengths of feedbacks** within and between multiple systems is also important for identifying potential tipping cascades (see Chapter 4.5).

4.2.1.4 PTP dynamics

This complexity of human systems makes it difficult to generalise about the process or dynamics of PTPs. Each system or subsystem is a unique and constantly changing arrangement of elements operating in its own spatial, temporal, social, ecological, economic, technological, political, legal and other contexts (Weber et al., 2023). Opportunities for PTPs may differ by geographical region or jurisdiction. For example, the use of mobile money for payments, banking and insurance has increased exponentially – following the classic S-curve of adoption – in many countries of the Global South (e.g. M-PESA in Kenya, adopted by 96 per cent of households within nine years of its launch). This is due to its accessibility and suitability for users in developing economies with little capital but high cash turnover and access to mobile phones. Access to M-PESA increases economic activity, financial resilience, saving and entrepreneurship, and is estimated to have lifted two per cent of Kenyans out of poverty between 2007 and 2014 (Suri and Jack, 2016). However, it is unlikely to disrupt the established banking systems in developed economies, where the majority of people have access to traditional banking services.

Despite the many different kinds of systems and contexts, positive tipping dynamics do exhibit common features and principles across systems and domains, as illustrated in Figure 4.2.3.

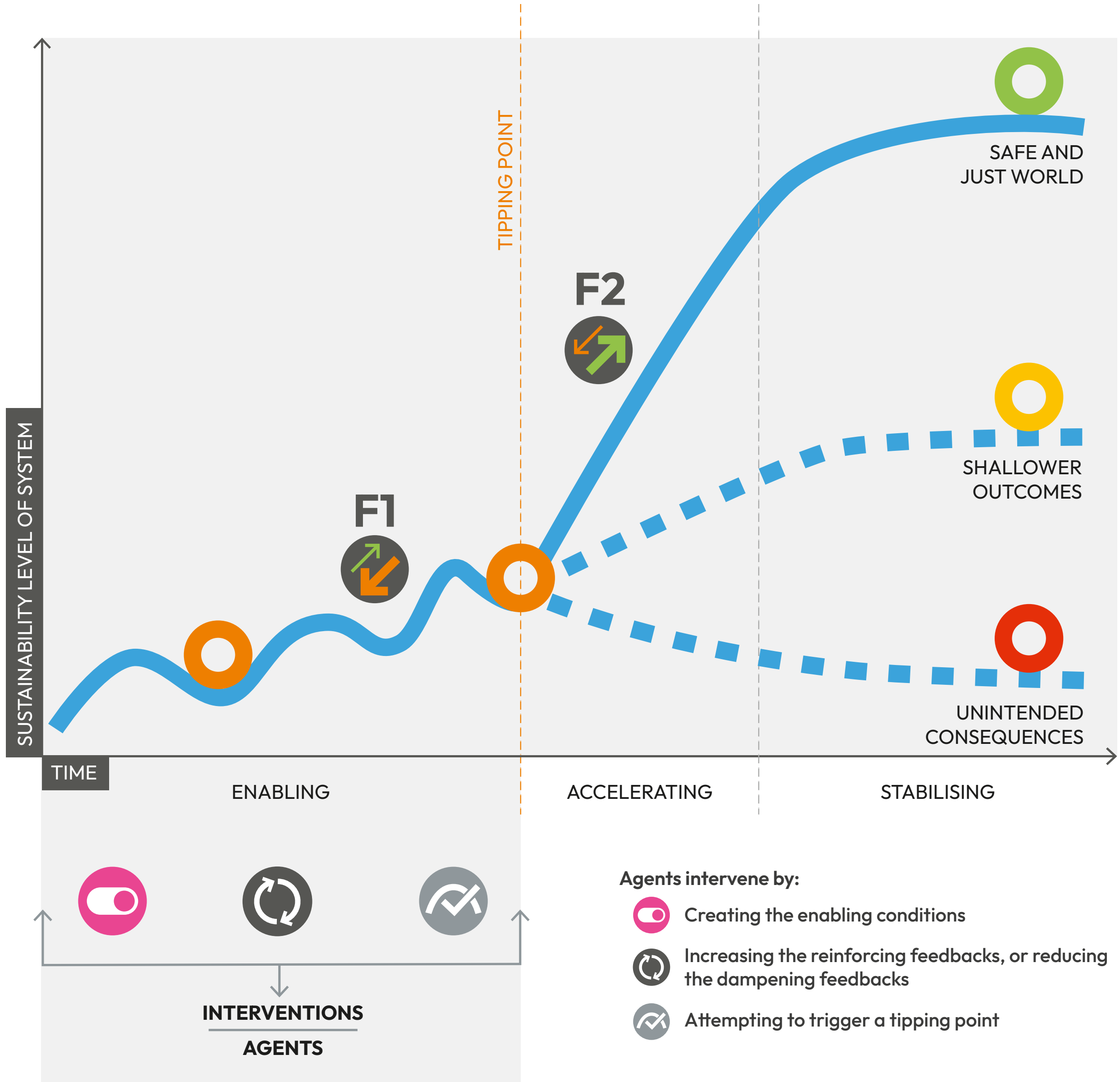

Figure 4.2.3: A conceptual framework for positive tipping points in human systems.

The current state of the target system is unsustainable. The desired outcome is consistent with a **safe and just world**. The process of positive tipping typically entails three different phases of **enabling, accelerating** and **stabilising**. To encourage the desired outcome, agents can strategically intervene to leverage change during the **enabling phase** in three ways, by: 1) Creating the **enabling conditions**; 2) Increasing the **reinforcing feedbacks** that increase the system's instability; or by decreasing the **dampening feedbacks** that maintain the system's stability; 3) Attempting to **trigger** a PTP. Once the **tipping point** has been crossed, the system enters an **accelerating phase** of nonlinear change dominated by **reinforcing feedbacks**, then **stabilises** again in a qualitatively different state. The primary characteristic of a tipping point is a shift in the balance of feedbacks: at **point F1**, prior to the tipping point, dampening feedbacks are dominant and system stability is maintained; at **point F2**, beyond the tipping point, reinforcing feedbacks are temporarily dominant and change accelerates exponentially. Other outcomes are also possible, including '**shallower**', less sustainable **outcomes**, and **unintended consequences**.

Mirroring the 'ascent' of sustainable innovations, PTPs also imply the 'descent' of incumbent, unsustainable systems (behaviours, practices, technologies and institutions). Whereas the tipping point for an innovative, sustainable solution marks the start of the accelerating, 'take-off' phase, it marks a 'cliff moment' of rapid descent for the incumbent system (Meldrum et al., 2023). Systems change might therefore be more accurately described as an 'x-curve', rather than the more familiar 'x-curve' (Loorbach et al., 2017).

The reverse, descending arm of the s-curve is composed of three phases – **destabilisation**, **breakdown** and **phase-out** – synchronous with the three phases of PTP dynamics. Interventions can be directed towards enabling or facilitating both of these processes (GSDR, 2023; Allen and Malekpour, 2023; Hebink et al., 2022).

We now examine the main PTP concepts in greater detail under the headings of agents, interventions, shallow and unintended consequences, and tipping cascades.

4.2.2 Agents

Human agency is the capacity of individuals or groups to change an outcome or course of events (Alsop et al., 2006; O'Brien, 2015). Agents (as policymakers, politicians, business leaders, activists, campaigners, artists, academics, investors, consumers or voters) can act, either intentionally or accidentally, individually or collectively, in ways that either assist or hinder social change (Newell et al., 2022; Gaupp, forthcoming). Individual and collective efficacy, or the belief that one's agency can avert threats or influence events, increases the motivation to act and enhances emotional wellbeing (Bandura, 1999; Feldman and Hart, 2016; Stern, 2018; Bostrom et al., 2019). Even small individual acts can lead to widespread collective effects – for example, the refusal of Rosa Parks to move bus seats in 1955, or the school strike initiated by Swedish teenager Greta Thunberg in 2018. Numerous studies and the history of social movements show that a committed and well-organised minority (between less than 3.5 per cent to 10 per cent of a population) can mobilise around a common aim long enough to exceed a critical threshold and transform a prevailing social structure – for example a social norm, law, institution or government (Chenoweth and Stephan, 2011; Xie et al., 2011; Rogers, 2010; Han, 2014; Marshall et al., 2018; Centola et al., 2018; Bolderdijk and Jans 2021; Constantino et al., 2022). Such social movements typically gestate in and benefit from 'free social spaces' (Törnberg, 2018) that protect them from the prevailing hegemony and actively cultivate and empower minority groups to challenge dominant agendas and narratives (Laybourn-Langton et al., 2021).

4.2.3 Interventions

As stated in Figure 4.2.3 and Table 4.2.1, agents can strategically intervene to encourage a PTP to emerge, by: a) creating enabling conditions; b) enhancing reinforcing feedbacks and neutralising dampening feedbacks; and c) providing the decisive trigger that pushes the system past its tipping point. Interventions can also be sequenced to create positive synergies – from innovation-oriented interventions that enjoy more political support to more controversial phase-out policies (Fesenfeld et al., 2022).

Table 4.2.1: Strategic interventions for triggering PTPs (Lenton et al., 2022). The three symbols correspond to those in Figure 4.2.3.

CREATE ENABLING CONDITIONS	INCREASE REINFORCING FEEDBACKS; REDUCE DAMPENING FEEDBACKS	TRIGGER POSITIVE TIPPING
Target smaller populations. Change social network structure. Provide information. Reduce price/cost. Improve performance and quality. Increase desirability or symbolism. Improve accessibility. Increase convenience. Coordinate complementary technologies.	Social contagion. Increasing returns to adoption: • Learning by doing • Economies of scale • Technological reinforcement Network effects. Information cascades. Percolation. Co-evolution. Ecological positive feedbacks. Social-ecological positive feedbacks.	Social innovation. Technological innovation. Ecological intervention. Social ecological technologies Policy intervention and public investment. Private investment and markets. Public information. Behavioural nudges.

4.2.3.1 Enabling conditions

Although the primary focus of attention might fall on the final, relatively insignificant input that triggers a tipping point, the reality is that many 'tippable' human systems first need concerted effort over a long period of time to generate the enabling conditions for transformative change to emerge (Lenton et al., 2022; Otto et al., 2020). For example, the cost of generating electricity using solar energy is now so low that capacity is expanding by more than 20 per cent per year (IEA, 2022). But this is the product of four decades of public investments, subsidies and other incentives. A new/niche technology, practice or behaviour needs to become more affordable, attractive, convenient, accessible, or morally acceptable than the established one before it becomes capable of displacing it. Generating these enabling conditions requires **strategically timed and targeted interventions appropriate to the system and focused on those elements that are most sensitive to change** (Mealy et al., 2023). For example, the widespread adoption of plant-based and planetary health diets likely requires a series of strategic interventions – labelling and other information schemes, changes in decision infrastructures, political advocacy, policy coalitions, financial and reskilling supports for the food industry, technological innovations, supply-chain restructuring, changes in dietary norms and habits, and so on – before such a major societal shift could emerge (Aschemann-Witzel and Schulze, 2023; Fesenfeld et al., 2022).

Most research, innovation and policy has until now focused on intervening in technological and economic domains – for example to enable a new renewable technology to achieve cost parity. However, PTPs in the socio-behavioural and political domains offer equally powerful opportunities for transformative change. For example, changing social norms could play a crucial role in enabling PTPs (Constantino et al., 2022; Schneider and van der Linden 2023). Social norms define acceptable behaviour and can change rapidly through a population. Two emerging examples that could prove pivotal to driving positive tipping points across multiple systems are **anti-fossil fuel norms** (Green, 2018), whereby fossil fuel use becomes socially unacceptable; and **norms that prioritise the avoidance of harm and sustainable sufficiency over material consumption** (Akenji et al., 2021; Newell et al., 2021; Haberl et al., 2020; Trebeck and Williams, 2019). In the political realm, policy can help create and spread new behavioural norms, for example by investing in infrastructural changes such as bike lanes (Yoeli et al., 2013; Nyborg et al., 2016; Lenton et al., 2022); or by strengthening climate education, arts and engagement that helps people imagine what a sustainable world would look like (Galafassi et al., 2018), and mobilises public support for greater action (Milkoreit, 2017; Stoddard et al., 2021; Plutzer et al., 2016; Otto et al., 2020; Bhowmik et al., 2020; Lenton et al., 2022).

Some PTP interventions are relatively straightforward and do not involve significant cost, innovation, social norm change, advocacy or diplomacy – for example, redirecting public procurement towards alternative proteins to help transform the food system (Meldrum et al., 2023). However, other potential interventions – for example, creating a global environmental court; removal of fossil fuel and animal product subsidies; a national or global network of deliberative mini-publics (DMPs) whose recommendations are fed into the policy system; or radical urban planning concepts such as 15-minute cities (4.3.2) (Otto et al., 2020, Moreno et al., 2021) – do involve significant cost, innovation, norm change, advocacy or diplomacy. For these more complex and radical interventions, a political process would first be needed to generate the coalitions and public support which, if successful, could then initiate a policy process. If this in turn is successful, the implemented policy may then transform the system and generate reinforcing feedbacks for further change (Figure 4.4.4). Positive tipping dynamics may therefore incorporate a **sequence of intermediary tipping points** on the way to the final goal or system state (Fesenfeld et al., 2022; Smith, 2023). Cross-cutting enablers in all domains may also be subject to their own tipping points.

4.2.3.2 Reinforcing feedbacks

As in natural systems, tipping points in human systems are driven by self-reinforcing (mathematically 'positive') feedbacks: an increase in a variable leads to a closed loop of causal consequences that further increase the same variable. For example, one person or organisation's decision to take the train rather than fly, or install solar panels, or pedestrianise a road, can increase the determination of others to do likewise. Such feedbacks are instrumental both in the enabling phase before a tipping point is reached and in the acceleration phase once a tipping point has passed (Figure 4.2.4). They can exist in any domain of human systems (social, economic, political and technological) and in their interactions with natural systems. For example, the self-reinforcing feedbacks of **economies of scale** and **learning by doing** have reduced the cost of solar PV and wind for energy generation to below that of coal power, with the result that most new power generation installed globally in 2022 was renewable (IEA, 2022).

Synergies between self-reinforcing feedbacks across multiple domains can help policymakers further enable the conditions for positive tipping (Fesenfeld et al., 2022, Pahle, 2018). Fesenfeld et al., (2022) highlight that synergies between policy-induced technological and behavioural changes can create self-reinforcing feedbacks and political conditions for positive tipping. For example, the German Renewable Energy Sources Act (EEG) triggered synergistic feedback effects in financial investment, technological innovation and cost reductions of renewable energy (Schmidt and Sewerin, 2018). Other self-reinforcing feedbacks associated with such policy interventions include shifts in public opinion, social norms and practices in favour of renewable energy, which in turn can reduce political opposition and create windows of opportunity for more stringent policy options, such as carbon taxation (Figure 4.2.4) (Fesenfeld et al., 2022; Lockwood, 2013; Schmid et al., 2019). Building on this logic in socio-technical transitions research, Geels and Ayoub (2023) distinguished seven feedback loops between behaviours of different social actors and technological changes in tipping dynamics.

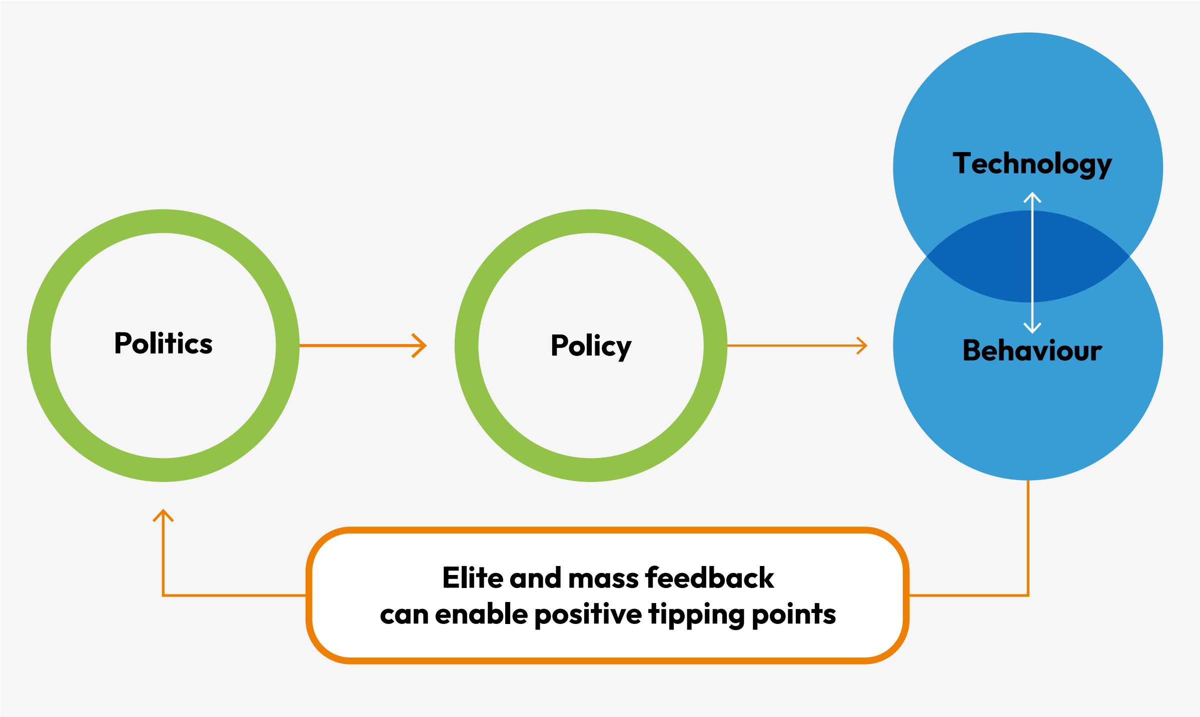

Figure 4.2.4: Reinforcing feedbacks from technological and behavioural changes can reduce existing barriers and enable PTPs (Fesenfeld et al., 2022).

Moreover, feedback and spillover effects between regions can play an important role in catalysing global change. For example, the German feed-in tariff created a first marketplace for solar PV panels that in turn has led to economies of scale in the production process of such panels in China. This has led to substantial cost reductions of solar panels so that PV became an attractive clean technology option at the global level. In turn, this has created a political momentum for change in other regions, such as China, the EU and US. In the transport sector, macro-economic modelling shows that mandates for switching to electric vehicles in major automobile markets such as China, the US or Europe can help to accelerate tipping points in other markets (Lam and Mercure, 2022).

4.2.3.3 Dampening feedbacks

As in natural systems, tipping points in human systems are prevented by dampening (or mathematically negative) feedbacks: a decrease in a variable leads to a closed loop of causal consequences that further decreases the same variable. Dampening feedbacks are system-stabilising forces. In the enabling phase, these forces – which in the case of human systems may be hegemonic political, social, discursive, economic, institutional or infrastructural – are typically still strong. They act as barriers to broader systems change. For example, in the political domain, the efforts of fossil fuel companies to obstruct, dilute, reverse or delay climate policy is well documented (Srivastav and Rafaty, 2022). In the socio-behavioural domain, a lack of trust or information, high perceived risk and uncertainty, institutional inertia, conformity, or ingrained habits may present barriers to people switching to more sustainable lifestyles (Rosenbloom et al., 2019; Constantino et al., 2022). Economic barriers to change may include high costs, supply-chain bottlenecks, or uncertainty surrounding future policy which delays new investment (Hamilton, 2009). In the technological domain, influential opposition may prevent the building of solar or wind farms. These and other forms of resistance, including system-preserving narratives based on excessive cost and over-regulation, should be expected to become more vocal and pervasive as system changes approach PTPs (Geels, 2014, Jost 2020).

A shift in the balance between dampening feedbacks (which maintain the status quo) and reinforcing feedbacks (which drive nonlinear change) can take a system out of its stable state and over a PTP, beyond which it enters an acceleration phase towards systemic transformation. Weakening the dampening (negative) feedbacks and/or strengthening the reinforcing (positive) feedbacks can bring a system closer to a PTP. The strategic sequencing of these interventions can also sometimes be important: for example, a policy process for radical change may first require a political process (4.4.2.4).

In this section of the report we focus exclusively on PTP systems. These are human (social) systems that **we want to tip** because this (in theory) leads to predominantly beneficial outcomes. We are not concerned with systems explored in Section 2.3 related to negative social tipping, where systemic change is unwanted because it leads to social harms such as war and social breakdown. Therefore, in this section alone, we can describe self-reinforcing feedbacks as being both normatively as well as mathematically 'positive'. Similarly, dampening feedbacks can be described as being both normatively and mathematically 'negative'.

4.2.3.4 Triggers of positive tipping

Any phenomenon that can be causally linked to a tipping point can be a trigger. This could be a deliberate social innovation, an investment or a policy intervention, strategically timed for maximum leverage or impact, and in awareness of the proximity of a tipping point thanks to early opportunity indicators (4.4.5). Alternatively, a trigger could be something incidental like a natural disaster or an epidemic, which causes a sudden shift in public attitudes and opens a window of opportunity for policy change. One example was the response of the German government to discontinue its nuclear power programme in the wake of the Fukushima tsunami disaster (Eder et al., 2023).

Mealy et al. (2023) argue that the most effective or 'sensitive' interventions should be executed when a system is close to tipping, the intervention thus acting as the decisive element or trigger. They propose a framework to help decision makers assess and prioritise interventions according to the assessment criteria, considerations and caveats presented in Table 4.2.2.

Table 4.2.2: A framework for prioritising 'sensitive interventions' close to a tipping point (Mealy et al., 2023).

Pillar	Key assessment elements	Other considerations and caveats
Trigger potential	**Criticality:** Does the intervention exploit a system that is close to a tipping point?	Does the intervention target a critical node in a network? Is this a critical point in time?
	Barriers: Are there barriers or resistance to the intervention, and can they be easily diffused?	Who stands to lose out from the intervention? Are there any other possible stumbling blocks or binding constraints?
	Lock-in and hysteresis: What prevents the change from being reversed?	Will a change in political leadership reverse the change? Does the intervention create path-dependency? Are actors in the system incentivised to keep the change in place?
Impact potential	**Size of impact:** Likely size of impact relative to cost of effort.	Size of impacts relative to costs can be difficult to quantify without a model that is able to capture nonlinear dynamics. However, rough estimates and expert opinion can also be useful (Lenton et al., 2008).
	Scales of impact: Potential to generate compounding change at greater scales.	Does the intervention lead to upward-scaling cascades across multiple system scales (e.g. sectors, geographies or social spheres? Does the intervention create synergies with other interventions, reinforcing the overall effect of change?
	Speed of impact: Timescale in which the intervention can be triggered and impacts realised.	Are the desired impacts likely to be realised at a time-scale relevant to address the problem (e.g. addressing climate change requires significant emissions reductions in the next few decades)
Risk potential	**Uncertainty:** What are the sources of uncertainty around the envisioned change process and associated impacts?	Are there examples where similar interventions have been tried in the past? Are there inherent sources of uncertainty that could put the viability of the intervention at risk?
	Unintended consequences: Could the intervention lead to impacts that are not intended or anticipated?	The risk of unintended consequences can be higher in complex systems that are sensitive to small changes in initial conditions or involve complex dynamics that are not well understood. Engaging with diverse groups of stakeholders can help bring to light unapparent unintended consequences.
	Trade-offs: Could the intervention or desired impacts cause adverse outcomes in other areas?	Are there any possibilities where the intervention or its impacts may create tensions or adverse impacts in other areas? If so, are there ways in which these trade-offs can be mitigated?

4.2.4 Shallow and unintended consequences

Interventions designed to induce positive tipping points towards safe and just Earth system boundaries can potentially lead to other outcomes that may be 'shallower' or insufficient (Pereira et al., 2023). Examples might include: changes to a system are not fully compatible with Earth system boundaries (ESBs); a social movement is assimilated into an existing power structure or regime before its aims are achieved; vested interests push for a suboptimal tipping point, for example the natural gas lobby pushing for hydrogen as the solution to future home heating when electric heat pumps are a far more efficient option. There may also be unintended consequences, which can negatively affect entire communities or regions. For example, in the rush to decarbonise transport and store electricity, the rising demand for lithium and cobalt for batteries can lead to heavily contaminated environments and shortage of drinking water surrounding mining communities, particularly in poorer countries. These areas have been labelled 'green sacrifice zones' because the environmental goods or services they provide also come with substantial costs (Zografos and Robbins, 2020; Hernandez and Newell, 2022). The report synthesis explores these risks, ethics and justice issues in more detail.

The speed of system change can be in tension or conflict with the 'depth' of positive change (Anderson et al., 2023; Newell et al., 2022; Skjølsvold and Coenen, 2021). The depth of change represents the extent to which the system is transformed into one that is sustainable or compatible with ESBs. The speed of transformation represents the time taken for the system to accelerate beyond its tipping point and re-establish itself in a new, qualitatively different stable state. These two forces are in tension when, for example, a sense of urgency to decarbonise as fast as possible leads to the further entrenchment of inequalities and injustices if policymakers are forced to rely on incumbent firms and investors to redesign systems in their own interests (Newell et al., 2022). The enabling conditions as outlined above must therefore consider policy architectures and forms of social engagement that neutralise these tensions.

4.2.5 Tipping cascades

A positive tipping cascade occurs when one tipping point triggers at least one other in a domino effect or chain reaction (Sharpe and Lenton, 2020). This can happen wherever tipping points occur – either in subsystems, where they can help accelerate change in a larger system, or across coupled systems (Chan et al., 2020). Coupled systems may be between domains, sectors, institutions and/or countries. The resulting overall multi-system impact of the initial change is larger than the initial impact as a consequence of reinforcing feedbacks and other secondary effects within and across systems, which is also referred to as **spiral scaling** (Newell et al., 2021; Geels and Ayoub, 2023). As elaborated in Chapter 4.4, some systems that have the potential for tipping can also be thought of and utilised as cross-cutting enablers of tipping in other systems. For example, there may be tipping points in the uptake of new electricity storage systems, digital technologies, social norms, political coalitions, or systems of finance; these can also be used, individually or in combination, as strategic interventions to enable tipping points in other systems. When designed to trigger a positive tipping cascade, such interventions are referred to as **super-leverage points** (Meldrum et al., 2023). As examples, economies of scale in the production of renewable energies can lead to tipping points in the adoption of electric vehicles, and thereby foster innovations in industry and agriculture; mandating Zero-Emission Vehicles can accelerate this process and create positive synergies with other potential super-leverage points, such as mandating green ammonia for use in fertiliser production. Cheaper renewable power reduces the cost of running electrolysers and reduces costs of green ammonia in fertiliser production. This, in turn, can lead to economies of scale in green hydrogen supply chains and bring down the cost of green hydrogen for use in several other sectors. To use a non-technological example, a social movement like Fridays for Future could create positive tipping cascades across sectors and jurisdictions if, for example, a series of school strikes were to inspire a general strike of workers organised by the trade union movement and professional associations.

In subsequent chapters we illustrate the practical application of this framework with empirically evidenced case studies in the sectoral systems of energy, transport, food and land use (see Chapter 4.3). We also investigate cross-cutting enablers of PTPs in socio-behavioural, political and financial systems, digitalisation and early opportunity indicators (see Chapter 4.4). The chapter after that (see Chapter 4.5) is a more detailed investigation of positive tipping cascades in a range of human systems.

Chapter 4.3 Positive tipping points in energy, transport and food systems

Authors: Tom Powell, Steve R. Smith, Caroline Zimm

This chapter takes a closer look at sectoral systems – energy, transport, food and land use. These sectors are key to accelerating decarbonisation, reducing short-lived climate forcer (SLCF) emissions including methane emissions, and enhancing biodiversity. The Intergovernmental Panel on Climate Change (IPCC) most recent assessment report (AR6) emphasises the need for rapid transformation in these sectoral systems. Successful mitigation pathways in the SSP scenarios require changes at least consistent with the best-case scenarios for past technological, behavioural or institutional change, and often depend on unprecedented rates of change. The feasibility of decarbonisation is shaped by barriers and enabling conditions across technological, economic, social-behavioural, political and ecological dimensions. These enabling conditions are context-dependent, but are essential prerequisites for propelling the fast technology and behavioural change required to achieve net-zero CO_2 emissions by mid-century.

In each sectoral system, we examine existing or potential PTPs, drawing on case studies and other research. Much previous focus has been given to tipping points in the technological domain, for example the substitution of fossil fuels for renewable energy sources, or of battery electric vehicles (BEVs) for those powered by internal combustion engines (ICEs). For these PTPs, reinforcing feedbacks associated with economies of scale, learning by doing and technological reinforcement are instrumental in driving down costs of low-carbon innovations and making them attractive to users. The Breakthrough Effect report summarised 10 potential positive tipping points across high-emitting sectors, and potential super-leverage points that could trigger positive tipping cascades. This subsection does not aim to replicate that work.

The Breakthrough Effect report and other studies have tended to focus on the mechanisms that enable low-carbon technologies to compete on economic terms, while acknowledging that important enabling conditions in other domains may also need to be satisfied. In reality, **positive tipping dynamics likely involve strong feedbacks between technological, behavioural, political and economic processes**, all of which can be important in enabling tipping into a new regime (Geels and Ayoub, 2023). Here we take a complementary focus to consider multiple other enabling conditions including, for example, how norms and behaviours or political processes can change to accelerate uptake of low-carbon technologies or other practices.

Likewise, previous work has largely focused on supply-side substitutions for the highest-emitting technologies or industrial processes. Markets for these technologies are, of course, determined by interactions between supply and demand. Thus, to better understand the conditions in which these markets might tip into new states, we also broaden the focus to consider the role of demand-side changes in enabling positive tipping points. While supply-side substitutions can drive powerful emissions reductions, they may not be sufficient, or efficient enough on their own, to meet climate goals. For example, cities are responsible for 70 per cent of global carbon emissions and two-thirds of energy use; thus, measures that transform energy use and transport in urban environments can have powerful mitigating effects (Winkler et al,. 2023) which reinforce efforts to decarbonise energy sources. We therefore also explore the potential for discreet PTPs in reducing or changing demand itself.

In this respect, an **avoid-shift-improve logic (ASI)** (Creutzig et al., 2022) is helpful in structuring actions, as the three types of action each have potential to reinforce the others by amplifying their effects. **Avoiding** aims at refraining from harmful activities or products – reducing unnecessary consumption, possibly by redesigning service-provisioning systems. **Shifting** describes a change to a less-harmful activity or product – a switch to efficient and cleaner technologies and service-provisioning systems. With **improving**, the product or activity becomes better in terms of environmental performance – the efficiency in an existing technology is improved.

Arguably the greatest overall positive impact is often achieved by avoiding the activity or product in the first place, and embracing the concept of **sufficiency** (Princen, 2005; Newell et al., 2021; Trebeck and Williams, 2019). However, in a global political economy that prioritises consumption-based economic growth, improving and shifting actions receive the lion's share of government and business support. Shifting tends to deliver less overall positive impact, with improving delivering the least. Hence, an inherent hierarchy within these approaches exist. While **improve** options are not sufficient to tip systems to a decarbonised state alone, they are an important enabler and amplifier of options that can. Any increase in efficiency reduces the need for **avoid** and **shift** activities. Similarly, smaller resource systems following **avoid** or **shift** interventions, need fewer **improve** actions to tip (Figure 4.3.1).

The different approaches and related measures can and should be combined – they are not mutually exclusive. While some are characterised by individual or collective behaviour change on the demand side, others are dominated by novel technology or facilitated by revamping underlying structures of a system. Typically, **avoid** and **shift** options require larger changes in social practices and in the broader socio-technical system.

Options where both behavioural and technological change is required or that require a substantial change in social and user practices are typically more difficult to realise and thus difficult as a starting point for tipping dynamics (Geels et al 2018).

The respective roles of avoiding (sufficiency), shifting (substitution) and improving (efficiency) also depend on the relative importance of behavioural and technological changes for enabling positive tipping in a particular sector (Fesenfeld et al., 2022). For instance, the widespread adoption of more plant-based diets is likely to depend on a combination of technological and behavioural changes along food supply chains and careful sequencing and synergies between **avoid**, **shift**, and **improve** interventions (4.3.3)

We use this logic to describe and organise interventions in this section and use these labels.

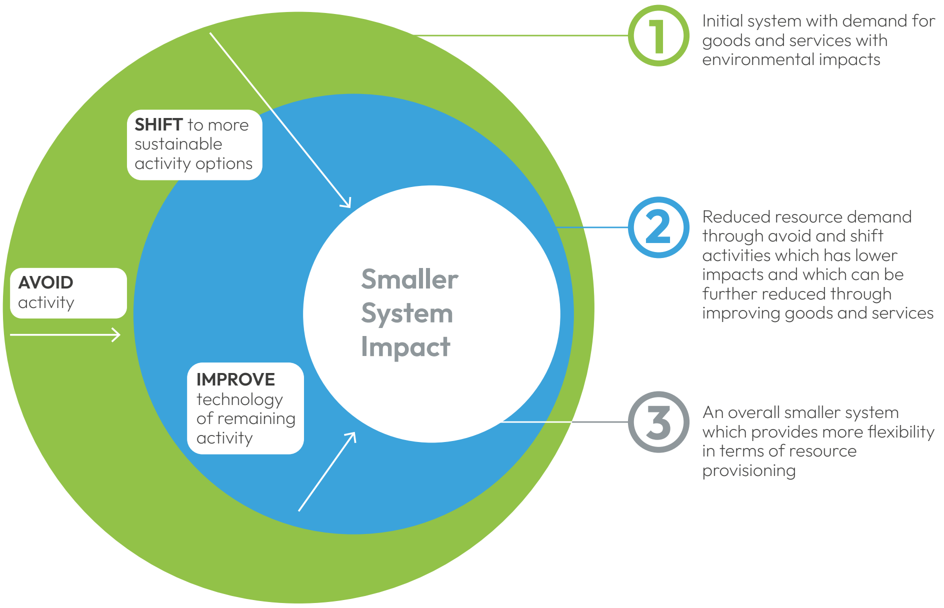

Figure 4.3.1: The avoid-shift-improve logic and how it connects to the overall system size which needs to tip. Systems are shaped by demand and supply options.

4.3.1 Energy systems

Authors: Floor Alkemade, Bart de Bruin, Francesco Pasimeni, Leila Niamir, Robert Wade, Franziska Mey, Johan Lilliestam, Raphaela Maier

Summary

The tipping dynamics in wind and solar power create potential for cascading effects to energy demand sectors, including household energy demand. These most likely start with shift actions and adoption of household-scale batteries and heat pumps. Key enablers are strong regulations incentivising reductions in demand and setting minimum efficiency levels for buildings and appliances. While there is evidence of spillovers to more environmentally friendly behaviour, the extent of these and the key leverage points present a knowledge gap. Moreover, these behavioural feedback loops require strong additional policy support to 'make them stick'.

Key messages

- For many countries the power sector has recently passed a tipping point in which the declining price of renewable electricity supply is reinforcing exponential growth, with over 80 per cent of new electricity generation in 2022 being solar and wind.
- Fast growth and declining price in renewable electricity supply is driving social tipping in the electricity system, as shown in the uptake of EVs, PV or heat pump systems and interactions between them.
- Reducing energy demand by identifying options to avoid energy-intensive activities, shifting to less energy-intensive activities and improving energy service efficiency can accelerate decarbonisation of the energy system.

Recommendations

- Further foster clean energy technology development and diffusion worldwide, especially in emerging markets.
- Enable positive tipping points in the adoption of novel technologies (shift and improve) and behaviours (avoid) with strong regulations that incentivise demand reductions.
- Set minimum efficiency levels for buildings and appliances.
- Encourage much-needed research on evidence of spillovers from one to more environmentally friendly behaviours and how to enable such spillovers.
- Implement strong additional policy support for behavioural feedback loops to 'make them stick'.

4.3.1.1 Introduction

The goal of energy systems is to provide energy services to end users. The main energy uses are for heat and electricity in industry and buildings and for transport (4.3.2). The industrial, residential and transport sectors together account for 70 per cent of the total global electricity consumption in 2019, and these sectors also are responsible for approximately 60 per cent of the worldwide carbon dioxide (CO_2) emissions (IEA, 2021a, IEA, 2023a). The decarbonisation of the energy system is a key driver of overall decarbonisation efforts. Energy systems are socio-technical systems; they consist of the technologies that generate energy and convert and deliver this energy to end users, but also of the actors and institutions that perform and govern these tasks. Within energy systems, the subsystems that can undergo tipping dynamics can be found in technologies, but also in social systems when actors and institutions change demand patterns (Geels, 2023).

Most consideration of tipping dynamics in energy systems concerns the price performance of different technologies (Otto et al., 2020; Sharpe and Lenton, 2021; Meldrum et al., 2023). Cost-parity has been reached and exceeded in many regions in a 'new-for-new' comparison of energy generation from wind and solar, versus incumbent fossil fuel generation, with the majority of new installed capacity in 2022 being renewable (IEA, 2022a; IRENA, 2023). In OECD countries, the resulting fast growth in wind and solar generation capacity has led to a reduction in fossil fuel demand in the electricity production, but not globally, as other nations increased fossil fuel demand (IEA, 2021b; OurWorldInData, 2022). Renewable energy generation sometimes faces curtailment and the mismatch of renewable supply with energy demand slows down replacement of fossil fuels, which benefit from their incumbent position. This shows that economic tipping points alone are not sufficient to realise rapid decarbonisation. Below, we explore how the tipping dynamics in wind and solar technology may initiate further positive tipping in the energy system, and we touch upon what this means for coal-intensive regions (Box 4.3.2) and we investigate advances relevant for industry (Box 4.3.2).

4.3.1.2 Fast growth in renewable electricity supply drives social tipping in the energy system

Cost reductions in renewable generation technologies like wind energy and solar photovoltaics (PV) have been much faster than predicted. Renewables are now among the cheapest electricity generation options (Haegel et al., 2019; IRENA, 2022a; IRENA, 2022b).

For wind and solar energy generation, the main reinforcing feedbacks that created these tipping dynamics are cost reduction and performance improvements through investment in research and development, learning-by-doing and economies of scale, leading to more deployment and, in turn, to more learning and price reduction.

(Sharpe and Lenton 2022; Kavlak et al., 2018, Nemet and Greene, 2022). The German feed-in tariff for renewables discussed in 4.2.1 was historically an enabling condition for a positive tipping point in the solar PV sector (Otto et al., 2020; Clark et al., 2021). Moreover, markets are still expanding as performance improvements make the technology attractive to a wider range of users. As a result of these technological improvements and cost reductions, renewable generation is increasingly possible in locations where wind or sun conditions are less favourable. The exponential growth of offshore wind power in the North Sea (Drummond et al., 2021; Geels and Ayoub, 2023) and the increasing attention for floating solar (Karimirad et al., 2021; Pouran et al., 2022) illustrates this. Renewable energy generation coupled with battery storage is expected to reach cost parity compared to power generation from natural gas in the near future, if it has not done so already (Meldrum et al., 2023), as battery costs are driven down by the growing electric vehicle industry, further enhancing the competitiveness of renewables with fossil fuels.

The cost-performance feedback loop is the main, but not the only, feedback driving the tipping dynamics for wind and solar. For instance, there is evidence for social contagion in the diffusion of rooftop solar PV, which is typically clustered in space where people are more likely to adopt when people nearby also have adopted (Graziano and Gillingham, 2015; van der Kam et al., 2018). This suggests that their diffusion is partly a social process influenced by, for example, **observability**, **trialability**, and **word-of-mouth** (Rogers, 2003) and **social comparison** (Bergquist et al., 2023).

Another reinforcing feedback loop stems from policy interactions, whereby policy creates legitimacy and new interests, leading to increased lobbying and support for policy (Roberts et al., 2018; Meckling, 2019; Rosenbloom et al., 2019; Sewerin et al., 2020). Further, strong pro-environment policies may incentivise firms towards more RandD and innovation, thereby expanding industrial sectors for low-carbon technologies. In this way, public opinion may also increase support and acceptance for new low-carbon technologies, increasing pressure on policymakers in creating goals and strategies for a more sustainable society (Geels and Ayoub, 2023).

Sources of dampening feedbacks, lock-in and path-dependence of fossil fuel-based energy systems include energy infrastructures, technologies and institutions (Köhler et al., 2019). These can directly hinder the decarbonisation of the energy system through existing standards and resistance from incumbents and vested interests. Indirectly, the availability of cheap energy has stimulated demand for energy-intensive goods and services. Similarly, the high return on fossil fuel investments and the assessment of renewables as risky require policy attention to stimulate the move of capital from fossil to renewables (Pauw et al, 2022, 4.4.4). As an example, in the early 2000s, the UK government provided initial capital grants to boost offshore wind demonstration projects, resulting in a game changer into the overall offshore sector. This has, in turn, built confidence among financial investors, easing access to resources for project developers (i.e. lower interest rates) (Kern et al., 2014; Geels and Ayoub, 2023).

Social dynamics can lead to reinforcing feedbacks but may also create dampening feedbacks when they mobilise opposition and a lack of societal support for larger-scale solar and onshore wind farms (Devine-Wright, 2007; Klok et al., 2023; Windemer, 2023). Cost-competitiveness is not a sufficient indicator to predict support for technologies for which the main public concerns are about spatial/visual impacts, health and safety, and questions of fairness.

Policy for positive social tipping can seek to strengthen reinforcing feedbacks and reduce dampening feedbacks. The policy-relevant timescales of the energy system vary from months to decades. Energy infrastructures are typically built for a lifespan of around 40 years, and changing these infrastructures takes place on the timescale of months to years. Once built, they contribute to stabilising the system state and are a source of path dependence and lock-in. In contrast, some demand-side behaviour changes are quite swift. An example is the substantial energy demand reduction in Europe in the winter 2022/2023, resulting from concerns about high energy prices and the war in Ukraine. A key policy challenge is how to make the new behaviour 'stick'.

4.3.1.3 Positive tipping dynamics that build on the fast growth in wind and solar technologies and services

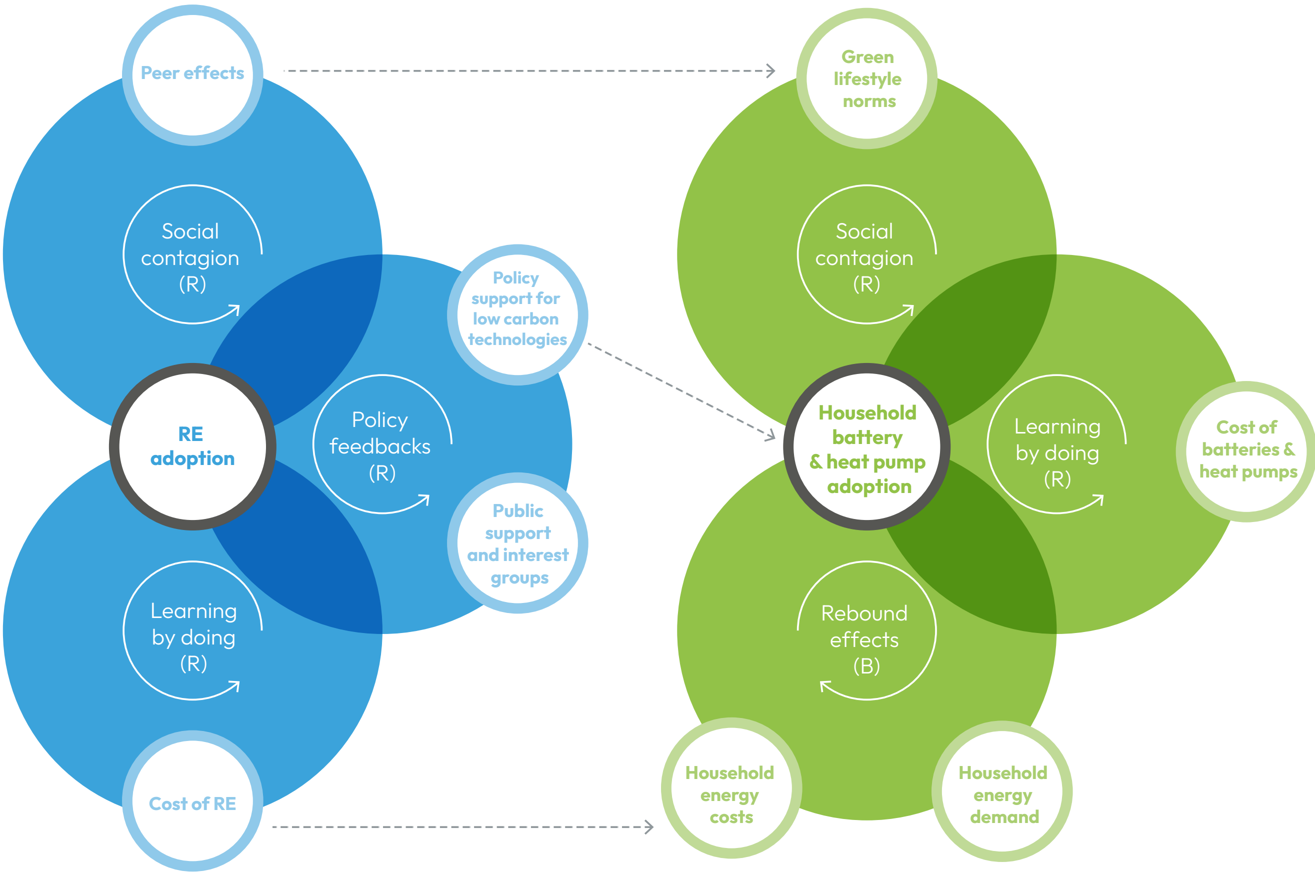

Figure 4.3.2: Cascading effects from renewable energy supply to household energy demand. The feedbacks that led to the strong growth in distributed renewable energy supply, can also strengthen the feedbacks that help reduce household energy demand when policy support is in place. R = reinforcing feedback, B = balancing/dampening feedback.

Two further significant developments are needed to transform the energy system. Firstly, while for many regions renewable energy potential exceeds demand, a fast energy transition faces constraints regarding the availability and sustainable sourcing of materials and personnel (Wang et al., 2023). Most scenarios therefore envision a reduction of demand where the demand for energy should be brought in line with what can be sustainably produced in the short term. Indeed, reducing energy demand is key in 1.5°C pathways (Koide et al., 2021). Reduction in energy use is thus widely regarded as a key pillar of decarbonisation in wealthy countries. At the same time, energy access and service provision will need to grow for many less-developed countries, and for poor people everywhere to ensure decent living standards and wellbeing (IPCC, 2022a). Although we observe a decoupling of energy demand and income in some places, in general household energy demand grows with income. Pro-environmental attitudes and behaviour have also been correlated with income, further complicating the challenge of how to reduce income inequality and material and energy consumption to sustainable sufficiency levels (Du et al., 2022). Moreover, individuals with high socio-economic status (top 10 per cent) are responsible for a large share of emissions (IPCC, 2022b; IEA, 2021b). These individuals could have a large positive impact when they reduce GHG emissions, becoming role models of low-carbon lifestyles, investing in low-carbon businesses, and advocating for stringent climate policies (Creutzig, et al., 2022). Such approaches are also discussed in the context of energy justice and equitable energy demand reduction (Büchs et al., 2023).

Second, when no low-cost zero-emission energy sources, like waste heat, are available, the energy system should electrify. In addition, but beyond the scope of this section, attractive technological alternatives like green hydrogen should be developed for hard-to-electrify demand (4.3.2).

To identify possible tipping dynamics and tipping elements in energy systems, we follow the avoid, shift, improve (ASI) logic (Creutzig et al., 2022, 4.3.1). While improve options are not sufficient to tip the energy system to a decarbonised state, they are an important enabler for options that can. Moreover, they may have important health co-benefits and reduce the material needs of the energy system. Any increase in efficiency reduces the need for avoid and shift activities. More generally, the different options often co-occur. While avoid options have the largest mitigation potential, they often need to be flanked with shift and improve options to be attractive. For example, when people switch from natural gas heating to heat pumps, good insulation (improve) is a condition.

Avoid options reduce unnecessary energy consumption. Changes in the energy behaviour of individuals can make a large contribution, specifically when supported by changes in the broader socio-technical system ranging from subsidies to norms for energy-efficient housing to educational and information campaigns (Nisa et al., 2019; Niamir et al., 2020). More specifically, social tipping of energy consumption by individuals, households or organisations is conditioned by a range of factors such as social and cultural norms, ownership and control of resources, technology accessibility, infrastructure design and services availability, social network structures, and organisational resources (Steg et al., 2018). Because of the relationship between income and energy use (Richmond and Kaufmann, 2006), a rebound effect may occur when technologically induced demand reductions lead to a higher budget and more energy demand (Newell et al., 2021; van den Bergh, 2011; Sorrell et al., 2020). While there is some empirical evidence for such a rebound effect (Berner et al., 2022; Brockway et al., 2021; Stern, 2020) – making decoupling of energy demand more difficult – decoupling has been observed in several Organisation for Economic Co-operation and Development (OECD) countries in recent years.

Digitalisation and AI can play a key role in avoiding unnecessary energy demand (Wilson et al., 2020; Giotitsas et al., 2022., see 4.4.4). At the individual and household level, lifestyle changes regarding energy demand, including turning down the thermostat and reducing the demand for hot tap water (shorter showers), are effective strategies (Roy et al., 2012; Creutzig et al., 2016; Ivanova et al., 2020). These are most effective when combined with policy support and shift and improve measures. More specifically, digital technologies are key to better match renewable supply with demand to prevent curtailments and grid congestion (load shifting and balancing) but have not yet reached widespread diffusion.

Higher prices (and temperatures) lead to reduced energy demand for heating. Natural gas consumption in the EU and in the period August-November 2022 decreased by 20 per cent compared to the average gas consumption for the same months in the previous five years (Eurostat, 2022). However, this also came with increased levels of energy poverty, particularly affecting low-income households in badly insulated homes (IEA, 2023b). Interestingly the high prices also triggered and opened the opportunity for sufficiency-based energy price interventions in the form of price ceilings for gas and electricity in response to the energy crises in the winter of 2022-2023.

When the demand reductions stem from changes in norms or behaviours with a sustainability motive, the risks of rebound effects are lower. Interestingly, **pro-environmental behaviours also induce other pro-environmental behaviours**, so changes in behaviour in mobility or food may spill over to energy behaviours (Steg and Vlek, 2009; Steg, 2023). The adoption of household PV for environmental reasons may thus induce other pro-environmental behaviours. As an example, evidence for Austria shows that the adoption of PV and electric vehicles are correlated (Cohen et al., 2019). When the new behaviour becomes common and the norm starts to shift, this also increases the **political feasibility of strict regulation**. There is, for example, public support for measures like incentives towards renewable technology and a ban on least energy-efficient household appliances (Poortinga et al., 2020).However, there is also evidence that these spillover effects are insufficient for the substantial lifestyle changes that are needed (Thøgersen and Crompton 2009; Truelove et al., 2016).

Empirical studies show that informing people about the energy conservation behaviours of their neighbours combined with the public labelling of energy conservation behaviour as desirable, can lead to significant reductions in energy consumption (Göckertiz, 2010; Allcot, 2011; Horne and Kennedy, 2017; Bonan, 2020). A key takeaway from these studies is that a relatively weak form of sanctioning (e.g., approval and disapproval of particular behaviour by using thumbs up/down or positive and negative 'smileys'), already has a modest positive effect on energy savings. Peer effects in social network structures can provide inhibiting or supporting conditions for the diffusion of energy conservation practices, depending on the structure of the network and the type of activity (Wolske et al., 2020).

If avoiding energy use is undesirable from a wellbeing perspective, then shifting the way this activity is done (or finding an alternative means to the same goal) is key. For electricity use, the decarbonisation of the energy system, driven by the cost reductions in wind and solar, is a large driver. Such reductions are more likely in smaller and more modular technologies (Wilson et al., 2020). Other small and modular technologies that may reach cost parity in the short term are household batteries and heat pumps (Meldrum et al., 2023). Household batteries are specifically attractive in places where feed-in tariffs for solar energy into the grid are much lower than the tariffs for energy from the grid (4.5.2).

The large-scale adoption of household batteries may influence the decarbonisation of the energy system in two ways: first, it reduces curtailment of household PV generation, better matching renewable energy supply with demand. Second, it reduces grid congestion during peaks in solar generation. Currently, in several countries, this congestion is a barrier to further grid integration of renewables. To stimulate demand to synchronise with the availability of renewable energy supply, utilities are offering dynamic tariffs that discriminate between time of use and sometimes also location of use (Nicolson et al., 2018; Freier and Loessl, 2022). These developments then further improve the attractiveness of household batteries.

The electrification of heating is a second technology that benefits from the fast decarbonisation of the electricity supply. For heat demand, which is often met by natural gas boilers (based on IEA, 2022b analysis, natural gas accounts for 42 per cent of global heating energy demand, with a 40 per cent share of the heating mix in the European Union and over 60 per cent in the US), the shift to low-carbon heat sources requires changes in technologies and infrastructure in houses, commercial buildings and neighbourhoods. When low-carbon heat sources like waste heat are available, this is a preferred option. When this is not the case, electrification of heating demand through heat pumps can lead to a large reduction in energy demand.

Here, important enablers are increased insulation (also to reduce overall heat demand) and increased renewable electricity supply. But, barriers are the lack of technologies for heat storage, the cumbersome installation process, and the high upfront installation costs. Supported by regulation and policy incentives, the demand for heat pumps is increasing fast in several countries (IEA, 2022c), providing further opportunities for cost and performance improvements through learning by doing. A more radical and politically challenging behavioural change would be to provide incentives to live in smaller homes or to have higher occupancy per dwelling, for example in planning decisions.

The cascading effect described above can contribute to energy demand reduction in rich countries. The declining cost of solar has also led to the development of solar home systems for energy-poor areas in the Global South, where off-grid solar technologies are estimated to be the least costly and most viable way to electrify the majority of those who lack access to electricity (IEA1, IEA2). Reliable access to electricity can unlock a cascade of benefits including access to cooking, cooling or heating, refrigeration for storing foods and medicines, lighting, power for agriculture, irrigation and other economic activities, and access to communications, banking and information. It plays a critical role in healthcare, sanitation and resilient livelihoods (PIDG report). A key barrier for enabling widespread deployment of solar power in the Global South is the high cost of capital in these economies – however, threshold and network effects in financial systems exist which could unlock investment (4.4.3.4). While in many of these countries the potential for solar energy, and for such systems to contribute to wellbeing, is large, the way they are packaged can fail to fit with local needs (Groenewoudt et al., 2020). Learning-by-doing is likely to play a key role in accelerating deployment, alongside continued support by international policy and investment to realise the potential benefits of solar at scale and develop local energy markets.

Box 4.3.1: Just energy transitions – tipping in coal- and carbon-intensive regions?

The socioeconomic transitions of coal- and carbon-intensive regions have raised concern for just transitions focusing on labour market opportunities. Essen and Duisburg in the German Ruhr Region, for example, have advanced in this transition process (>30 years) in different ways. Both cities experienced incremental changes in their demographic, economic and political trajectories. We can also identify a bifurcation in the cities' visions and their narrative development: Essen envisions a green, sustainable future, whereas Duisburg remains devoted to its industrial storyline. Neither of the cities have crossed a tipping point in the hard quantitative indicators (e.g. unemployment rate, GDP) yet the narrative change may indicate a significant and qualitative shift in the long term: if the cities embark on different trajectories now, this will likely result in stronger social and economic differences in the future. Maybe seen from a few decades into the future, the period around 2020 can be identified as a tipping period in one or both cities.

Successful examples exist where renewable energy stepped in when the fossil fuel industry declined. In Denmark, Esbjerg was a major port for the oil and gas industry. It was specifically targeted by the Danish Government to be a major beneficiary of the new offshore wind sector. Today, one in nine jobs (5,000 in total) in Esbjerg is related to wind power. The town received dedicated policy support for just transition which can be replicated elsewhere. Offshore wind has been revitalising communities in the North East of England that were left behind when coal mines closed in the 1980s. Offshore wind development now offers high-skill level jobs and opportunities for economic development and export-oriented local supply chains through investment in local facilities and communities. The UK is the largest off-shore wind power market in Europe. For just energy transitions benefiting communities, local value-creation will be key.

Box 4.3.2: Decarbonising the steel sector

The global steel industry is responsible for 7 per cent of greenhouse gas emissions (OurWorldinData, 2023) and needs to decarbonise quickly, by adopting low-carbon technologies instead of blast furnaces. Three scales are relevant here: the whole global steel industry, individual steel companies, and their specific production facilities. The ultimate goal is to see a tipping point at the global scale, which means a significant decrease in emissions across the industry. This will only happen when specific companies or facilities tip first. When some pioneering companies decide to switch to low-carbon technologies, it could set off a chain reaction. Currently, 11 full-scale green hydrogen DRI steel plants are planned to be operational by 2030, and once around 6 per cent of steel plants make this change, the prices of these technologies is expected to drop, making them more accessible to others, and emissions will start to decrease. Carbon pricing or equivalent subsidy can accelerate the point at which green steel becomes competitive with fossil fuel-based production (Meldrum et al., 2023). This process takes time, but it is crucial for the long-term goal.

How to trigger tipping points at the individual company level is the more urgent concern, in order to enable this wider tipping point. This happens when a company decides to commit to a net-zero pathway by using low-carbon technologies instead of fossil-based practices. The evidence for a potential tipping point is even stronger when the decision is backed by concrete plans for technology implementation and investment in new infrastructure.

One example is voestalpine, an Austrian steelmaker that decided to reduce emissions by replacing parts of its blast furnace process with green hydrogen-based direct reduction and electric arc furnaces (voestalpine, 2023a). This move shows the beginning of a positive feedback loop, pushing the company further along the path to net-zero emissions when new technologies become more common.

Political and economic factors also play a role. EU and national policies, such as the emission trading system, put pressure on companies to reduce emissions. When customers demand low-carbon steel products, it drives innovation and motivates steelmakers to provide more low-carbon options. These factors can trigger tipping, pushing the industry closer to the net-zero goal.

4.3.2 Transport and mobility systems

Authors: Luis Martinez, Leila Niamir, Aneeque Javaid, Keith Smith, Joshua E. Buxton, Aileen Lam, Caroline Zimm, Tom Powell

Summary

The transport sector is one of the most difficult to decarbonise, currently still relying almost entirely on fossil fuels for individual motorised transport. While individual technologies such as electric vehicles (EVs) show promising acceleration in their diffusion to support decarbonisation of this sector, transport demand is ever increasing. Merely switching to a new technology for passenger vehicles will not transform our mobility in a sufficiently sustainable manner as other externalities will prevail and material demand will remain high. Aiming to avoid demand for material-intensive mobility and shifting to more active modes of transport play a key role in transforming this sector. Examples of successful initiatives that moved towards more active mobility modes, such as walking and cycling, and higher-capacity technologies, are given with a focus on passenger mobility in cities. Bus Rapid Transit Systems are low cost and high impact and have been replicated in some cases both in Global North and Global South contexts. An example of how freight transport could be transformed is also given.

Key messages

- There is an urgent need for a large-scale tipping point in transport demand as demand for freight and personal transport continues to increase, with diverse negative impacts.
- EVs show evidence of passing or approaching tipping points in major markets including China and Europe, following the pioneering example of Norway.
- There are encouraging localised examples of tipping points in urban mobility, a decrease in individual motorised transport, and a shift to more active transport modes which can be upscaled.
- Decarbonisation in the sector will not happen without a behavioural adaptation of society to a new consumption and growth paradigm.

Recommendations

- Policymakers need to prioritise integrated planning to enable tipping in transport, foremost regional planning for public transport and active travel infrastructure to avoid material-intensive individual mobility.
- Policymakers need to steer the transition of the transport sector with tools such as zero emission vehicle mandates, which can induce EV tipping points across markets.

4.3.2.1 Introduction

The transport sector faces enormous challenges in meeting the decarbonisation targets in the following decades. Transportation worldwide is responsible for 23 per cent of global GHG emissions (ITF, 2023), still relying heavily on fossil fuels (91 per cent) (IEA, 2023). Its emissions are growing and it is the slowest sector to transform and adapt to a new reality (Creutzig et al., 2015), with infrastructure and vehicle fleets supporting lock-ins and path dependency. Freight (46 per cent of transport emissions) and passenger transport (54 per cent) are closely linked with the global economy and perceived wellbeing. This raises the question of how perceived wellbeing can be decoupled from unsustainable modes of mobility.

Interventions or policies in the transport sector that could allow moving towards decarbonisation and provide a smoother and more robust pathway rely on the avoid-shift-improve framework (Creutzig et al,. 2022). Figure 4.3.3 presents the current system of policies and investment that needs to be inverted to increase the attractiveness of sustainable transport and public transport against car dependency, urban sprawl and long-distance travel. For transport systems, **avoid** focuses on measures that could help reduce demand for mobility by adapting consumption and activity patterns. **Shift** looks at the possibility of moving demand from carbon-intensive modes to cleaner zero-emission alternatives (e.g. public transport, biking, battery electric vehicles). And **improve** aims at increasing efficiency by meeting the same demand, yet reducing emissions through improving vehicle performance or promoting cleaner energy sources. Most recent measures and policies put in place or which have been promoted strongly for the next decades focus on the latter.

Improving the efficiency of vehicles, such as switching from internal combustion engines to EVs (4.3.2.2.), which have significantly lower lifetime emissions (Knobloch et al.,2020) (see Chapter 4.6), will contribute to achieve the decarbonisation targets and interfere less with how markets and society operates as underlying structures only have to adjust a little, but it will not be enough and also omits other externalities (e.g. traffic, material requirements). The challenge resides in the recent technological improvements that enhanced vehicle efficiency, reduced costs and generated more induced demand for mobility and transport than the CO_2 they mitigated. Energy demand for passenger transport can be lowered by up to 73 per cent when combining **avoid** and **shift** approaches, achieving several co-benefits and improving wellbeing simultaneously (Arz and Krumm, 2023). Combined with **improve** options for the remaining part, urgently needed decarbonisation could be achieved in time.

For this reason, this chapter will also discuss enabling conditions to tip the transport system and transport-related policy measures and innovations that could significantly bring down transport emissions and promote other sustainability concerns, such as liveability and resource-use efficiency, in the coming decades.

First, this chapter looks at passenger transport, summarising current understanding of the EV transition and then focusing on avoid and shift solutions in urban areas. Next, the chapter provides examples of technological advances that could transform freight transport. The examples are scalable and come with several opportunities for reinforcing feedbacks.

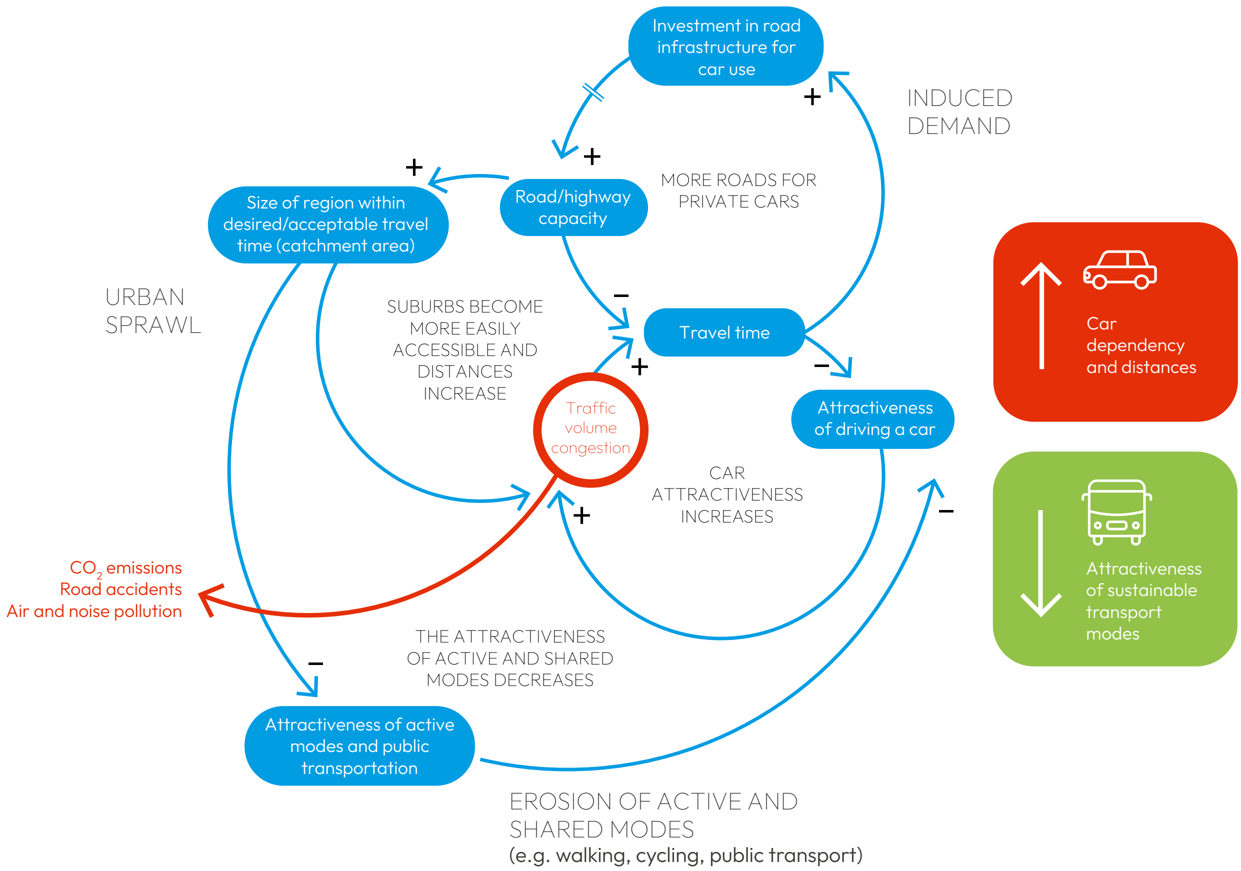

Figure 4.3.3: Causal loop relation of the vicious cycle of urban expansion and related transport regimes that need to be broken to reduce car dependency and increase attractiveness of sustainable transport modes. Higher urban sprawls increases the attractiveness of private cars and more roads for cars, which again leads to more sprawl and car ownership. Source: OECD, 2021

4.3.2.2 Improving passenger transport with the transition to electric vehicles

Sales of EVs, including battery electric vehicles (BEVs) and hybrid electric vehicles (HEVs), have increased rapidly in many national markets. Consequently, market share of internal combustion engine vehicles (ICEVs) has been declining in North America, Europe and Asia as EVs have further diffused. This regime shift in Europe and Asia has been rapid, with the two markets appearing to have undergone a tipping point, and EVs on track to rapidly capture more than 50 per cent of market share. So far however, the EV transition in North America does not appear to have reached a tipping point (Figure 4.3.4).

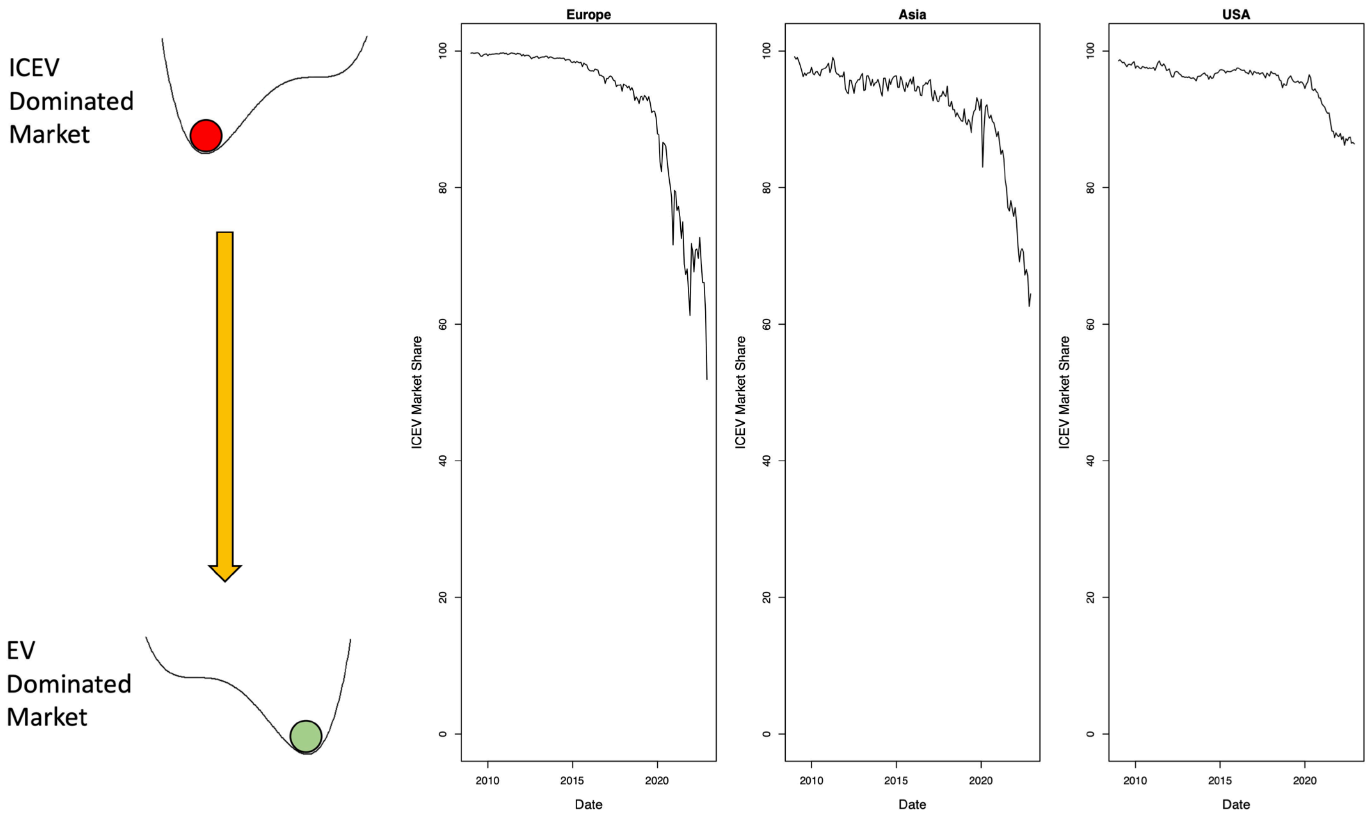

Figure 4.3.4: *I*CEV Market Share in the Europe, Asia and the USA, alongside a cartoon representing the alternate ICV dominated and EV dominated stable regimes which may exist.

Drivers of change

The EV tipping point has been enabled by factors involving technological innovation and economic developments, but also changes in policy intervention and public perception (Geels and Ayoub, 2023). There is a link between the unit volume of technology produced and the cost of production (i.e. learning rates), as has been demonstrated for solar PV and wind production (Way et al., 2022). The reduction in cost of production is driven by the reinforcing feedbacks of economies of scale and learning-by-doing.

This reduction in cost, as well as improvements in the technology, makes the technology more attractive and accessible to those who may purchase it, thus creating a positive feedback loop which can drive the rapid deployment of these technologies (Sharpe and Lenton, 2021; Farmer and Lafond, 2016; Lam and Mercure, 2022). BEVs have already passed tipping points in price parity of ownership with ICEVs in EU and Chinese markets, and are likely to do so in other key markets of the US and India by the mid to late-2020s (Figure 4.3.5). In most markets, tipping points for price parity at the point of purchase are also likely to be crossed before the end of the decade (Lam and Mercure, 2022).

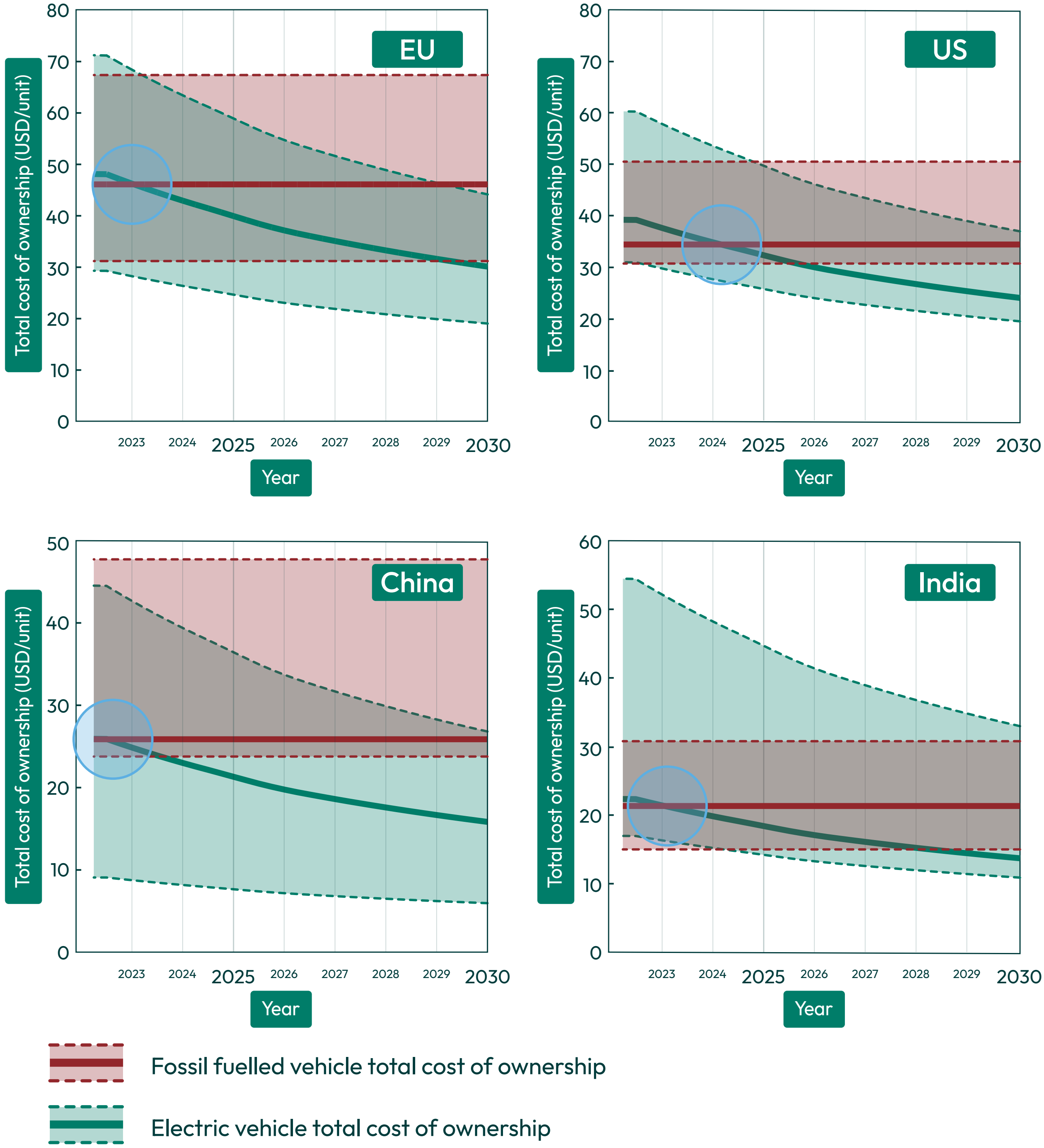

Fig 4.3.5: Tipping points for the cost of BEV ownership relative to ICEVs in major global markets. Source: Lam and Mercure, 2022

The key remaining barriers to adoption are (perceived) average driving range and battery charging time, and deployment of charging infrastructure. Range and charging time are continually improving, driven by the same reinforcing feedbacks as drive down overall costs, with the average range of new BEVs increasing 9 per cent per year from 2015-2021, however they are still some way off performance parity with ICEVs (Meldrum et al., 2022). Installation of public EV charging infrastructure is still lagging in many key markets, but is accelerating in leading countries.

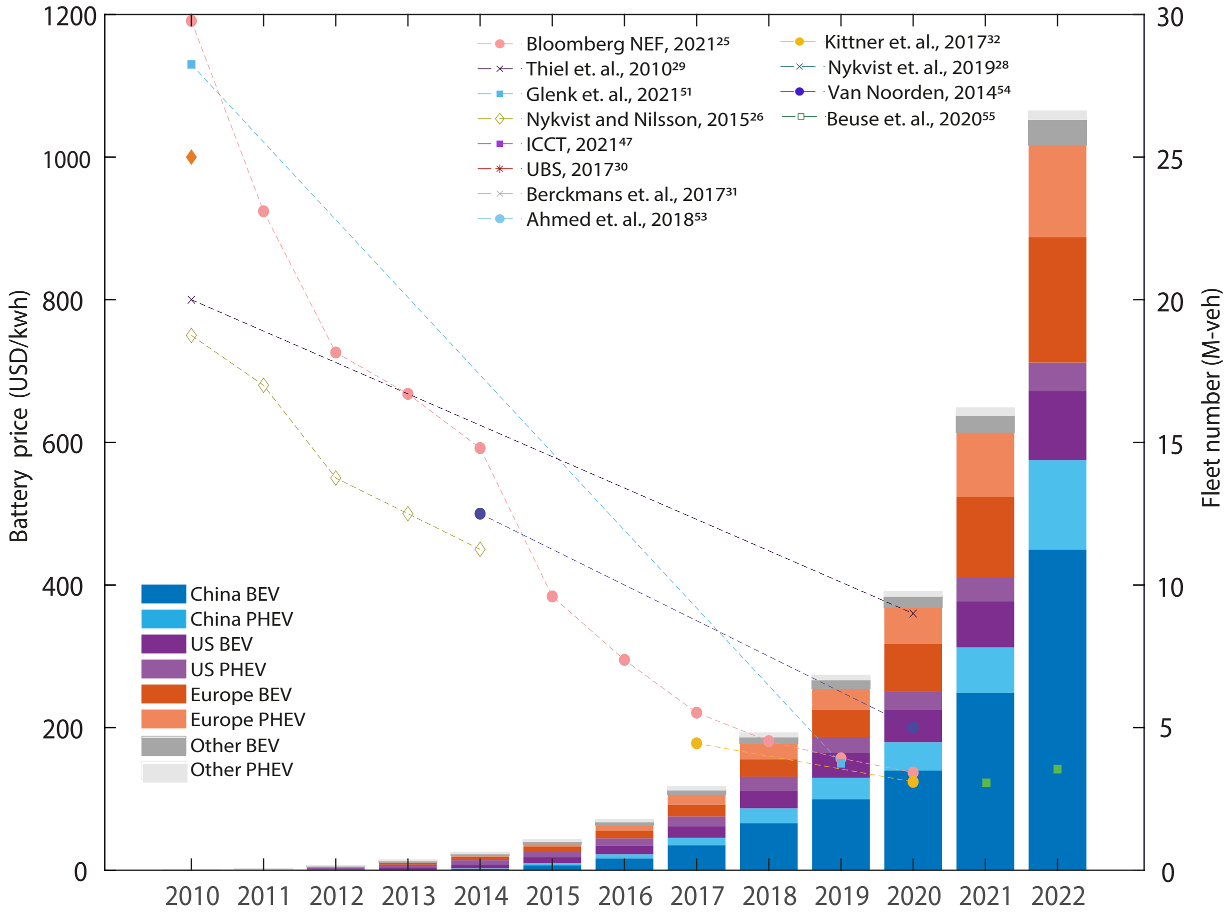

Figure 4.3.6: Exponential growth of sales of BEV and PHEV in China, US and Europe and the corresponding decline in battery price. Source: Lam and Mercure, 2022

As sales in EVs and PHEVs have increased since 2010 across three of the major global markets, the price of batteries has also declined (Figure 4.3.6). It is possible that, as EVs become widespread, this trend will continue; although some questions remain around mineral price volatility and how this will affect battery prices. Deployment of charging infrastructure is also growing exponentially, keeping pace with growth in EV sales (IEA).

Policy interventions can also assist in the diffusion of new technologies by reducing cost or mandating changes. Norway has become a classic case study of the successful transition from ICEVs to EVs, having been the first country to make this switch. One factor in driving this change was a tax system which ensured that EVs were cheaper than comparable ICEV models (Sharpe and Lenton, 2021), thus making them more attractive to consumers and leading to a rapid diffusion. Zero-emissions mandates at national and state level ensure a reduction of ICEVs within fleets and are likely the most cost-effective policy to drive the transition and contribute to this EV transition (Bhardwaj et al., 2022,; Lam et al., 2023). Due to the internationally connected nature of the automotive sector, EV mandates in major markets could induce, or bring forward, EV tipping points in other markets due to reduced sales prices (Lam and Mercure, 2022).

The effects of the EV tipping point are unlikely to be isolated just to the automotive transport sector. EV deployment will lead to an extensive charging network and is likely to have a significant impact on battery capacity, with consequences for renewable energy storage and production (Meldrum et al,. 2023). These cascading effects are discussed further in Chapter 4.5.

As indicated, improving transport modes alone will not be sufficient as this does not tackle the overall system size, including material needs, traffic and so forth. Tipping in shifting transport modes and avoiding travel are needed.

4.3.2.3 Shifting to enhanced active mobility

Shifting to walking and cycling is known as active mobility and known as active mobility or **non-motorised transport** (NMT), significantly increases human wellbeing and health through lifestyle changes, where individuals engage in physical exercises and enhance social cohesion, a reinforcing feedback that can lead to more demand in NMT (Hanson and Jones, 2015; UNEP, 2018; Marques et al., 2020; Mansoor et al., 2015). Such a shift can be enhanced through different enabling conditions, with prominent examples following here.

Appropriate infrastructure (Figure 4.3.7), including protected pedestrian and bike pathways, can support much greater localised active travel (IPCC 2022; Creutzig et al., 2022; Brand et al., 2021; Neves and Brand, 2019; Zhang et al., 2018) and, together with more compact urban design, can reduce urban GHG emissions by around 25 per cent. In addition, e-bikes and e-scooters have seen accelerating uptake and could unleash huge future potential in cities' mobility, leading to reduced congestion and emission reductions (Asensio et al.,2022).

Cities with cycling strategies, such as Copenhagen and Amsterdam, show how to prioritise non-motorized transport. In its dedicated cycling plan, Amsterdam prioritises cycling through infrastructure and regulations which strives to 1) keep bicycle traffic flowing smoothly; 2) improve bicycle parking; and 3) encouraging considerate cycling (Pucher and Buehler, 2007). Amsterdam is a safe and bike-friendly city, where even toddlers and older people use bikes as the most accessible mode of transport (Feddes and de Lange, 2019). Studies show that cycling is distributed evenly across all income groups for all trip purposes, that cycling rates fall only slightly with age, and that Dutch and Danish women cycle as often as men (Pucher and Buehler, 2007).

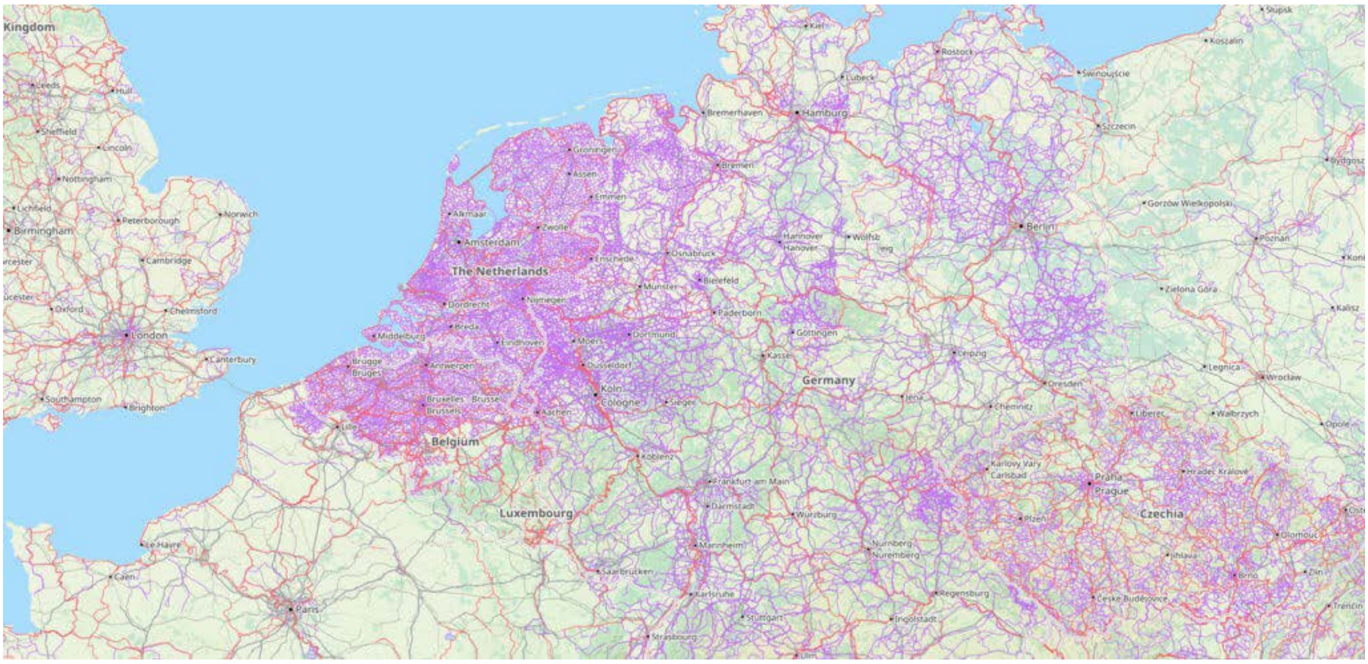

Figure 4.3.7: Bicycle path density In the Netherlands and neighbouring countries. (Open cycle map)

Active mobility narratives differ in the Global South context (Mansoor et al., 2022). More than 75 per cent of total daily trips made by Africa's low-income population are made by walking, compared with 45 per cent by more affluent groups (African Commute, 2018). Ethiopia, Kenya, Uganda and South Africa have set up policies to increase non-motorised transport recognition and accessibility, aiming to create a safe and comfortable environment for pedestrians and cyclists (Nairobi Metropolitan Services, 2020; City of Cape Town, 2005, 2017, 2020, 2021), and also aiming to improve air quality in cities. Replication across more regions and cities could lead to several positive feedbacks.

COVID-19 lockdowns have spurred significant trends in urban mobility, with several reinforcing feedbacks: a rapid expansion in 'pop-up' (temporary) urban cycling infrastructure (Becker et al., 2022; Creutzig et al., 2022; Kraus and Koch, 2021), electronic communications replacing many work and personal travel requirements (4.4.5); and revitalised local active transport and e-micro mobility (Goetsch and Quiros, 2020; Newman, 2020; Department of Transport UK, 2021; SLoCaT, 2021). The challenge so far has been the 'stickiness' of these changes in the longer term.

Infrastructure and policy design are two key enablers of positive tipping points for active mobility adoption. Peer effects, then, can add on positive and wished feedbacks to accelerate behavioural change (4.4.1). Combining infrastructural enablers, such as compact cities that avoid lengthy trips (Box 4.3.3), fair streets (which feature more space, design and services for walking, bikes and other micro-mobility) and bike/scooter-sharing schemes, with social enablers such as bike training, actions to generate a new culture (Jittrapirom et al., 2023) and policy design (e.g. carbon pricing, subsidies) (Matteoli et al., 2010), get us to the positive tipping point faster. The estimation of infrastructural and social tipping points vary and strongly depend on geographical, environmental, cultural and political context. One key variable is policy readiness: the availability of worked-out detailed policy plans that advance modal shift ready to be implemented when an opportunity occurs (Creutzig et al., 2022).

There are several success cases worldwide in achieving significant changes in mobility patterns and its externalities, the case of Pontevedra in Spain (Box 4.3.3) being one of the most notable for its vehicle restriction policy. **Vehicle restriction schemes** set a 'cordon' (i.e. a low-emission zone: usually a city centre or a whole city) restricting access for a subset of the vehicle fleet for specific periods or uses to reduce congestion, traffic speeds and/or pollution, and provide better access to non-motorised mobility modes.

Dampening feedbacks of such policies – even if only temporary – are related to social acceptability and the backlash this change can bring when the desire to own a car is spurred. This regulatory instrument can be categorised as shift to move mobility towards cleaner transport modes (Cloke and Layfield, 1996).

Box 4.3.3: Changing urban mobility – the case of Pontevedra,

Pontevedra in Spain, a city of around 100,000 inhabitants, stands out as a successful implementation of emission reduction in the transport sector in the Global North. Surface parking was removed and traffic calmed across the city, limiting speeds to 30km/h, adapting the pavement to slower speeds, and reducing traffic segregation with priority to pedestrians and cyclists as well as introducing roundabouts. The town developed walking maps (Figure 4.3.8) similar to metro maps to help people move quickly and promote active mobility. The impact of reduced mobility externalities, such as traffic, noise and pollution, has been immense and aligned with a solid public acceptance of the measures and improvement of the city's economy and vitality. Since 1996, CO_2 emissions have been reduced by over 70 per cent (~88 per cent downtown and ~47 per cent expansion area) Nieuwenhuijsen et al., 2023; Jimenez-Espada et al., 2023).

Pontevedra succeeded in changing the urban landscape, converting the car to a guest in the city and not the main actor, increasing liveability, revitalising the economy and positively affecting local population dynamics, as well as reversing the population loss of previous decades. The elements that created enabling conditions of this positive tipping point were the political courage of the mayor, technical and expert assistance to convert the whole city into a reduced traffic zone, the involvement of citizens in decision making and the design of the final solutions, with intense workshops to help people adapt their lifestyle and downgrade private cars in the priority of city space use. **Spain**

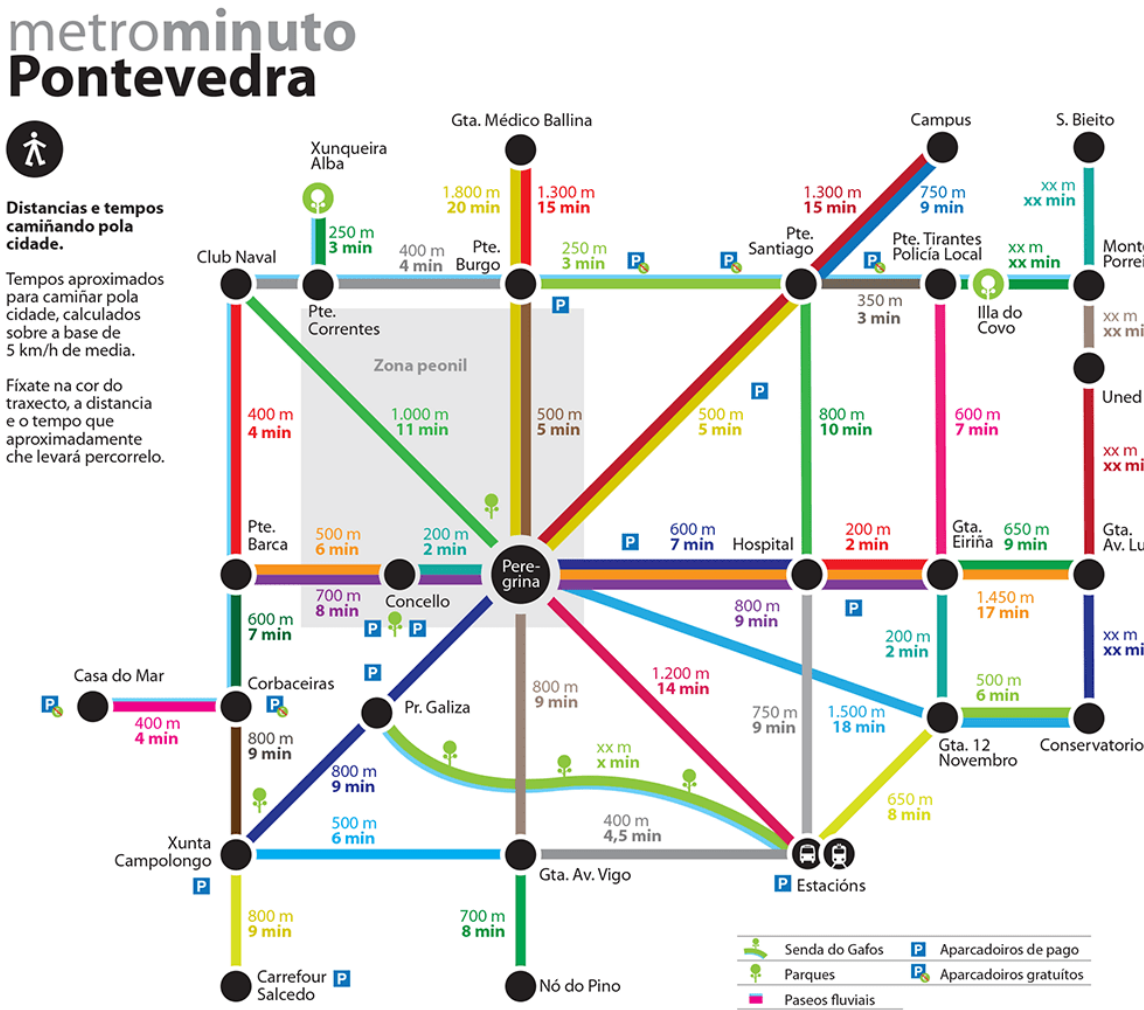

Figure 4.3.8: Tipping to active mobility by turning perspectives and providing tools to the population. A schematic walking map of the city of Pontevedra showing the distances and walking times to reach different places in the city.. (Source: https://metrominuto.pontevedra.gal/es/#features)

The level of success seen in Pontevedra (Box 4.3.3), which treated private cars without any differentiation, has yet to be achieved elsewhere, where lack of alignment of political will, consistency, technical support and citizens' involvement prevail. Implementation with partial plate-control systems to differentiate between user groups does not work, as cities including Athens, Milan, Oslo, Paris, London and Rome have shown. These partial restrictions are mainly aimed at air quality control and reduction in CO_2 emissions (Kuss and Nicholas, 2022). The policies were limited to certain types of vehicles or times of the day or certain number plates allowed to circulate for certain days of the week. These policies differ significantly in ambition and achieved impacts compared to Pontevedra.

In the Global South, several cities, such as Beijing, Jakarta, Mexico City and Bogota, have successfully implemented partial vehicle restriction programmes. With air quality improvement being the primary goal, CO_2 reduction and transformation of the mobility behaviour are perceived as a co-benefit but not the primary objective of the measures.

To achieve the radical change needed for a paradigm shift in urban mobility habits, public institutions need to provide firm and consistent political leadership and ensure public participatory processes, as well as smart land use, with high densities (>4000 inhabitants per sq km) and land use mixtures to allow inhabitants to use non-motorised mobility for most of their activity (e.g. compact or 15-minute cities). The municipality in Pontevedra implemented its public space management in less than one year. To replicate it in more cities and of different sizes will require tailoring to unique challenges while preserving the idea of reducing the hierarchical role of private cars in urban mobility.

Another example of change facilitation in urban transport is the concept of **Mobility as a Service (MaaS)**. By supplying a wide range of personal transport services, including bike and car-sharing, car rental, underground, rail and bus, through a single digital customer interface, MaaS can alter travel behaviour and demand (more details in 4.4.5.). A full implementation of this concept at the urban scale, linked with other measures such as vehicle restriction schemes, can be a game changer of the urban ecosystem and allow people to have better life quality by reducing costs, urban space devoted to cars, pollution and other externalities. The development of this concept will also be linked to the advance of infrastructure development, urban transport services diversification (4.3.2.4) and business models that provide users with more sustainable options.

4.3.2.4 Enhanced heavy capacity public transport networks

To cover longer distances, cities need alternative approaches to active mobility options. Bus Rapid Transit (BRT) systems have features similar to light rail or metro systems and are thus faster, more reliable and convenient than regular bus services. The main attractiveness of BRTs lies in the low cost compared to rail-based transit systems while providing relatively high mobility services (e.g. right-of-way, reduced congestion and accessibility of more distant stops). Yet, taking the decision to invest in such a public transit system remains risky for policymakers as the benefits are dispersed across many people over time and upfront investment remains high. Operational BRT systems, ideally from nearby or socio-economic and geographically similar cities, must be available as examples to learn from. Once a pool of such BRT systems exists, the likelihood of other cities adopting the approach increases. Such a demonstration effect in the diffusion of innovations shows how important successful fore-runner projects are for fundamental transformations – especially for large-scale infrastructure projects which systematically change a city's mobility system in the long term.

Box 4.3.4: Curitiba's Bus Rapid Transit System – an example to learn from

Curitiba, Brazil, was an innovator in developing its BRT system. Like other developing cities, Curitiba's initial master plans relied on cars to satisfy the growing mobility needs of its population. However, from the 1960s onwards, a fear of the ever-increasing resources needed to satisfy the demands for automobile-oriented mobility led city policymakers to embrace a public transit-oriented growth model to provide good, reliable public transit options at manageable costs for a city with limited means.

Curitiba's bus system is hierarchical, with the BRT system running along the city's main arteries connected by feeder buses spread across the city. This star-like structure enables public transit while preserving access to green areas and parks, simultaneously achieving climate mitigation and adaptation objectives (Pierer and Creutzig, 2019). It has been popular and effective in generating a modal shift away from cars to public transit (28 per cent of users previously travelled by car), with an estimated reduction of about 27 million car trips per year. Citizens from across the income spectrum use the system and have greater mobility. In Curitiba, about 30 per cent less fuel per capita is used compared to other cities in Brazil, resulting in one of the lowest rates of ambient air pollution in the country and lower transport-related GHG emissions. A reduction of traffic crashes compared to similar cities could be attributed to the BRT as it has led to more compact urban growth and increased land value around BRT lanes and stations (Lindau et al., 2010).

This contagion effect has been shown for BRT systems (Kitzmann et al., 2022): Following Curitiba's successful example (Box 4.3.4), several cities developed early BRT-like systems. Initially cities in neighbouring countries in Latin America followed a typical spatial diffusion pattern. This changed with the introduction and subsequent popularity of Bogota TransMilenio, which inspired cities across the globe to adopt BRT systems. Further momentum was created by systems springing up in Guangzhou in China, Ahmedabad in India, and Istanbul in Turkey. The popularity of BRTs is not limited to low and middle-income countries; cities in the European Union (e.g. Bus-VAO in Madrid, Spain) and the US and Canada (e.g. Metro Rapid in Los Angeles or B-Lines in Vancouver) have also adopted BRT systems modelled on the early pioneers in Latin American cities. Given the differences in quality attributes among the systems as well as the overall traffic and socio-cultural situation in cities where BRT has been implemented, not all of them are successful, with the system in Delhi, India being a prominent example of a poorly implemented system that has been rolled back due to opposition from certain sections of the population (Kathuria et al., 2015).

Globally there is evidence that implementing BRT systems leads to a significant increase in public transport usage and modal shift of up to 30 per cent at city level, with users preferring it over standard buses, creating a more satisfied customer base that is less likely to abandon it once private vehicles are an option. BRT stations often facilitate transit-oriented development with increased residential and business densities, a diversity of land uses and, thus, shorter distances to trip destinations. These systems are also associated with greater mobility for disadvantaged groups, especially women, for example in Lahore, Pakistan.. There is enormous potential for large public transit infrastructure to bring about a shift in female mobility in cities of the Global South.

Beyond BRT, examples of rail-based systems' disruptive effects on urban mobility can also be found in the Global North (e.g. Porto, Portugal) and Global South (e.g. Johannesburg, South Africa) (Curtis and Scheurer, 2019). Both cases showed a huge emission reduction potential by producing a strong **shift** towards cleaner public transport, reducing private car use, and **improve** by increasing transport efficiency by increased load factors, and cleaner energy use.

As with active mobility, the introduction of such public transport systems can make people rethink their (future) choice of using private vehicles for their mobility needs, impacting also inter-city and long-distance travel. Transport-related choices are influenced by social norms (4.4.1): with an increasing number of people relying on public transport (or active mobility) for their mobility needs, their peers are motivated to adopt similar behaviour. With this combination of changes in individual-level habitual choices and social norms, infrastructure developments can change societal attitudes towards sustainable mobility (4.4.1). Like in the positive feedback loop for individual motorised transport (Figure 4.3.3), once sustainable mobility infrastructure is introduced, more people rely on this infrastructure, thus creating demand for increased spending on this infrastructure and greater accountability to ensure policymakers meet these demands.

Globally, there is large potential for shifting urban mobility to options of public transport systems and active mobility. This has not yet been harnessed, with tipping lacking at large scale, but several successful examples exist which could be replicated if the enabling conditions were in place.

4.3.2.5 Positive tipping points in other transport systems

This chapter has focused on individual transport and tipping in urban contexts. Inter-city or long-distance passenger or freight transport and related indications of tipping opportunities have been discussed elsewhere previously (Meldrum et al., 2023).

A tipping point for electrification of heavy-duty road transport (i.e. freight), responsible for three per cent of global emissions, is a more distant prospect than that for EVs as it depends on considerable development in battery technology and charging infrastructure deployment to become competitive on cost. Once price parity is reached, however, tipping is very likely due to the strong economic incentives for business to reduce distribution costs. Strong policy to support development of charging infrastructure is likely to accelerate tipping. Other systemic changes can also play a powerful role in avoiding freight emissions by increasing efficiency, which would further reduce the costs of electrification (e.g. Box 4.3.5).

In aviation, tipping to using synthetic, power-to-liquid (PtL) fuels is a possibility, dependent on significantly reducing the costs of production to be competitive with fossil fuels. This requires considerable investment in development as PtL fuels are currently nearly four times the price of kerosene jet fuel. Reaching a tipping point likely depends on a mixture of regulation with carbon pricing and/or subsidy; policy support is currently emerging in the US and EU, and may help to drive cost reductions and scaling. Opportunities for tipping cascades related to green ammonia and fertilisers exist for the shipping sector (Meldrum et al., 2023) (4.3.3. and Chapter 4.5).

Box 4.3.5: Asset sharing and digital platforms to tip freight transport

Asset sharing is a resource-sharing concept in road freight that facilitates available volume or weight capacity in trucks to other companies by a common data platform that contains routing plans and can match requests and available supply, aiming to optimise load factors. Digital information and communications technologies (ICTs) and the creation of common data platforms facilitated this concept (4.4.5) and several pilot case studies have shown the huge potential for companies, especially if distributing goods with no special transport requirements (e.g. temperature control) (Ballot and Fontane, 2010).

From an environmental point of view, sharing assets can increase logistic efficiencies – for instance, by increasing the occupancy rate of vehicles. Shifts towards less carbon-intensive modes are also possible, where bundling several companies' freight creates a viable traffic flow. Ultimately, improvements that lead to load consolidation can reduce the number of trips required to deliver products and reduce the emissions linked to logistics activities. Reductions in emissions can be very significant, as shown in trial studies in the UK, with up to 40 per cent savings (Wang et al., 2015). Other studies, such as the EU-funded CO^3 project - Collaboration Concepts for Co-modality - found savings from horizontal collaboration to be above 15 per cent. A partial collaboration project modelled the impacts of multilateral co-operation on CO_2 emissions to be around 14 per cent. In Belgium, a collaboration between three firms could lead to a 25 per cent reduction of the number of delivery trips (Vanovermeire et al., 2014). Countries in the Global South have also already promoted some trials in urban contexts, such as Bogota, where a collaborative network of shared delivery routes and depot infrastructure was identified as having a 25 per cent CO_2-saving potential. Other urban consolidation studies showed a huge potential for shared assets in cost savings (approximately 50 per cent) as well as CO_2 emissions (40 per cent) (Nataraj et al., 2019).

Most of the trials and initial platforms so far have been from private initiatives, but governments may consider appropriate competition regulations to facilitate such asset sharing towards a Physical Internet (PI). This concept is an open, shared global logistics system based on a physical application of the principles of the digital internet. Individual logistics networks would no longer be operated by one transport service provider, but rather by one global transport network using shared hubs. Competition among companies would focus on products rather than logistics and supply-chain extent and efficiency. Such a system would require new standardised modular packaging units, standard protocols and tools, and shared logistics and digital assets. The change in logistics systems is still nascent and trials are emerging. Regulatory frameworks are needed for a full-scale implementation globally and locally, providing incentives or penalties for inefficient or uncooperative behaviours that lead to additional use of resources. PI could disrupt the entire existing logistics chain, providing a positive tipping opportunity.

4.3.3 Food systems

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Summary

Transforming the food system is critically important to meeting Paris Agreement targets, protecting biodiversity and achieving the Sustainable Development Goals (SDGs). Three key leverage points to mitigate food system impacts are illustrated by case studies: **reducing consumption of livestock products** by shifting to more sustainable diets; **avoiding food loss and waste**; and **restoring critical ecosystem service provision** through improved farming practices.

For dietary change, shifting behavioural norms and consumer experiences in high- and middle-income countries is key, and can be accelerated by policy choices and public procurement that increases exposure to low-livestock meal options. A positive tipping point in attractiveness and affordability of alternative proteins can help to accelerate this shift. Diffusion of alternative business models and income-sources for livestock and feed producers, e.g. in agri-photovoltaics, can also accelerate changes in livestock supply chains. To reduce food loss and waste, coordinated action by public and private initiatives can create reinforcing feedback and have transformative effects. To change farming practices, policy certainty and robust markets for ecosystem services can incentivise farmers to change, but strong information networks are critical.

For climate vulnerable people in the Global South, this shift can lead to social-ecological reinforcing feedbacks that build social, economic and ecological capital. Together, these leverage points offer opportunities to reduce pressure on natural ecosystems, restore natural carbon sinks and increase social justice. Strengthening deliberative food system governance, science-policy interface and effective sequencing of policy can help to accelerate transformation.

Key messages

- There are strong synergies between key leverage points for achieving climate goals, biodiversity protection and other SDGs. These leverage points are avoiding food loss and waste, shifting to more plant-based diets, improving alternatives to animal products, and shifting to agro-ecological farming.
- Triggering food system positive tipping points could be encouraged by a greater focus on adaptive and deliberative governance, a stronger science-policy interface, science-based targets and strategic policy design and sequencing to help support those who might otherwise be 'losers' in positive tipping points, such as livestock farmers.
- The key leverage points require coordinated political and social action to change norms, accelerate innovation, disrupt dampening feedbacks and provide incentives.

Recommendations

- Combine and sequence private and public interventions to create nonlinear reductions in food loss and waste. Examples include consumer apps and nudging in public cafeterias, supermarkets and restaurants and regulatory and incentive instruments that target retailers as central actors in the food supply chain, fostering reinforcing feedbacks.
- Focus on policy synergies along the supply chain (i.e. nudges, public procurement standards and innovation-oriented measures) to foster demand-side shifts in public cafeterias, restaurants, and supermarkets towards more plant-based diets, while providing incentives to producers and processors to shift towards plant-based food production.
- Integrate policies that foster innovation and diffusion of alternatives to animal products to drive positive tipping points through cost reduction, improved availability and quality, and social norm shifts.
- Make agroecological practices or alternative land uses economically attractive to farmers by diversifying business models through well-regulated markets for payments-for-ecosystem-services (including carbon), or other innovations like Agri-PV. Reducing administrative burden (e.g. via satellite-based and outcome-based subsidies), and offering compensation schemes can also reduce barriers and political backlash.
- Focus policies incentivising production-shift, new emission-pricing (e.g., nitrogen surplus fees and methane emission trading), phase-out and compensation schemes on large producers in key regions (e.g. regions and farms with excessive nitrogen pollution or organic soils). New revenues from emission pricing should be used to support most affected regions and low-income groups (e.g., via reducing VAT rates on plant-based food), foster innovation in alternative proteins, and create additional income sources for farmers. This can help to negotiate a feasible, efficient, effective, and just transition package.

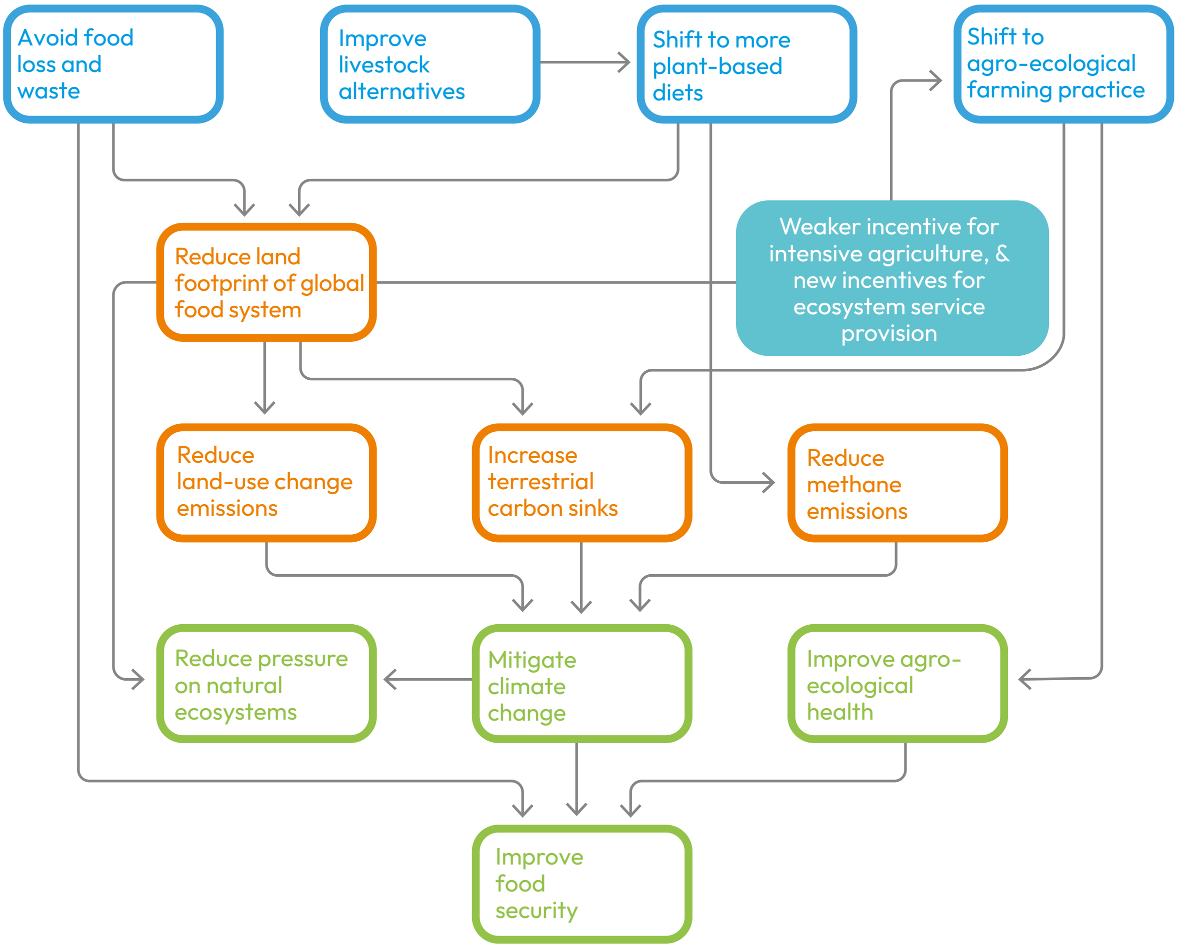

Figure 4.3.9: Avoiding food loss and waste, shifting to more plant-based diets and improving farming practice through agro-ecological approaches are key leverage points which can interact to produce a cascade of benefits for natural ecosystems, climate change mitigation and food security.

4.3.3.1 Introduction

Globally, food production is responsible for about 25-30 per cent of anthropogenic greenhouse gas emissions and is a major driver of biodiversity loss via land use change, degradation and deforestation (Ritchie,Rosado and Roser, 2002; Ritchie, 2021; Poore and Nemecek, 2018). Moreover, the food system-related emissions of short-lived climate pollutants such as methane (Fesenfeld, Schmidt, and Schrode, 2018) and agriculture-driven tropical deforestation (Pendrill et al., 2022) can accelerate tipping points in the Earth system, such as the dieback of the Amazon rainforest (Armstrong McKay et al., 2022). Production of animal products is a key driver of these impacts, via their own land use and methane emissions, and via the additional feed required to produce them in intensive systems (Pendrill et al., 2022; Poore and Nemecek, 2018; Springmann et al., 2018).

The food system is not only a direct cause of the global climate and ecological crises, but is itself profoundly affected by them; globalised value chains are under increasing pressure, threatening food security and political stability worldwide (Pörtner et al., 2023). Diverse crises in the past three years, such as the COVID-19 pandemic and the Russian war in Ukraine have led to food price inflation and challenged the resilience of the global food system (Bai et al., 2022; Bogmans, Pescatori, and Prifti 2022; Sperling et al., 2020). The wave of anti-government protests, uprisings and violent conflicts that began in 2010, collectively known as the 'Arab Spring', may also have been triggered by food prices (2.4.4.4).

Defining priority targets for food system transformation in line with the SDGs, Paris and Biodiversity Agreement

Sustainable transformation of food and land use systems is urgent to comply with the Paris Agreement (UNFCCC, 2016), and is also required to meet multiple international goals beyond this, including the SDGs (UN, 2015) and the Kunming-Montreal Biodiversity Agreement (Ainsworth, 2022; Allievi et al., 2019; Niles et al., 2018; United Nations, 2019). While in the short term certain trade-offs may exist between environmental, social and economic goals (Scherer et al., 2018), there are many positive synergies (Creutzig et al., 2022, Doelman et al., 2022) which can enhance reinforcing feedbacks; and trade-offs can be minimised by focusing on key priority targets and leverage points in food systems (Kroll, Warchold, and Pradhan, 2019). For example, avoiding food loss and waste and shifting to more plant-based diets and agro-ecological farming practices are key leverage points.

Accelerating positive change

The pace of progress is not sufficient, but positive tipping points may be able to unlock rapid and cascading change to accelerate transformation of food and land use systems (Pharo et al., 2021; Lenton et al., 2022; Fesenfeld. P. et al., 2022). The food system is a complex web of interactions across scales and sectors; from local scales between ecosystems, producers and communities, up to global scales between the biosphere, international markets, and technologies. As well as technological innovation, social norms and culture are important drivers and barriers for behavioural change across the food system. And the policy landscape, including taxes, subsidies and regulations, plays a key role at all scales (Fesenfeld et al., 2023; Pharo et al., 2021). All these interactions can be part of self-reinforcing feedback loops which can drive change for a more sustainable food system.

Many food system elements can have further cross-sector interactions – for example with energy and transport systems, which can generate either dampening or reinforcing feedbacks. Production of ammonia for fertiliser, for instance, is a globally significant energy use, currently contributing between 2 per cent and 5 per cent of greenhouse gas emissions; however, ammonia production has potential as an early market for green hydrogen (Box 4.3.6), which could in turn help to generate economies of scale that enhance its viability in other sectors (as discussed in Chapter 4.5 and in Meldrum et al,. 2023). Such cross-sectoral spillovers and cost reductions in technological learning, such as agri-photovoltaics and green-ammonia, can be mutually reinforcing and lead to potential tipping cascades (Fesenfeld L. et al., 2023; Meldrum et al,. 2023).

Box 4.3.6: A tipping point for green ammonia

Production of ammonia using renewable electricity, or 'green ammonia', is expected to be a significant lever for decarbonising fertiliser production, with at least 10 projects either operational or coming online in the near future (Meldrum et al,. 2023. Green ammonia production takes advantage of existing learning curves and rapid expansion in renewable energy deployment, and is also subject to a learning curve of its own. As the sector scales, a learning rate of up to 18 per cent cost reduction per doubling of output is expected (IRENA, 2020), and in turn lower costs are likely to drive greater deployment. Price parity with 'grey ammonia' is likely to represent a tipping point, and could be accelerated to be achievable this decade by a carbon price or equivalent subsidy of around $100 per ton CO_2. It should also be noted that, in addition to improving ammonia production, emissions from fertiliser use can also be avoided by up to 70 per cent by optimising fertiliser use through practices such as improved crop rotation, precision application and dietary shifts (Systemiq, 2022).

Deliberate, rapid transformation of the global food system is not a novel idea. The Green Revolution (Box 4.3.7) comprised a set of initiatives launched in 1965-1966 with the aim of enhancing agricultural production and ensuring food security in the face of a growing world population. This concerted effort demonstrated remarkable success in reducing malnutrition and hunger, though it also led to inequalities and unintended consequences that remain important today.

Box 4.3.7: Historic case study for tipping points in the food system: The Green Revolution

The 'Green Revolution' describes initiatives launched in 1965-1966 that aimed to enhance agricultural production and ensure food security in the face of a growing world population. These included the introduction and widespread adoption of new agricultural technologies and practices such as high-yield crop varieties, synthetic fertilisers and pesticides, the expansion of irrigated land, and mechanisation. The Green Revolution also had a strong political dimension. Governments made boosting agricultural production a priority and coupled public policies supporting farmers with technology development to address hunger and malnutrition with great success. Yields grew substantially in the subsequent decades, resulting in nonlinear increases in agricultural productivity. In the 50 years since the beginning of the Green Revolution, the global population doubled from 3.5 billion to 7 billion people, while cultivated land expanded by a mere 12 per cent (Alston and Pardey, 2014; De Schutter, 2017).

The Green Revolution had broad implications for the food system. It sparked a transformation in farming practices, from traditional subsistence farming to intensive, industrialised agriculture, dominated by economies of scale. This was accompanied by changes in land use patterns, water management strategies and consolidation of agricultural supply chains. The Green Revolution served as a catalyst for innovation in agricultural research and development, and led to the establishment of dedicated institutions and funding mechanisms for research and innovation. It also fostered collaboration between scientists, policymakers, and farmers, building information cascades which disseminate agricultural knowledge and technologies.

While the Green Revolution brought about nonlinear increases in productivity, it also raised concerns about its sustainability. Since 1990, the rate of agricultural productivity growth has notably slowed (Alston and Pardey, 2014), suggesting the possibility of reaching a plateau in productivity in high- and middle-income countries.

Widespread use of synthetic inputs and the focus on monoculture farming has led to environmental degradation, soil erosion, loss of biodiversity and increased vulnerability to pests and diseases. Increasingly subsidised food production, which did not internalise external costs, also led to increased food waste and loss and allowed widespread adoption of diets that are inconsistent with human and planetary health. For instance, substantial subsidies directed towards major grain producers have resulted in the availability of large quantities of low-cost feed inputs for meat production. This, in turn, has fostered an overconsumption of meat in many affluent countries (Hawkes, 2006;De Schutter, 2017).

Increasing use of new technologies and fertilisers also led to growing demand for capital and ultimately created more market concentration. Large retailers had an increasing preference for sourcing from prominent wholesalers and processing firms, resulting in 'mutually reinforcing dual consolidation' (Farina et al., 2005). These self-reinforcing feedback mechanisms contributed to the concentration of power and resources within food production and distribution chains as global supply chains expanded (Gibbon, 2005). In turn, larger market players could exercise increasing political influence, shaping the way agricultural subsidies were tailored to specific types of producers, products and production methods.

The Green Revolution stands as an example of a tipping point in the transformation of the food system. It revolutionised agricultural practices, boosted productivity and alleviated hunger and poverty on a global scale. However, it also demonstrates how tipping points can lead to suboptimal 'shallower' and unintended consequences that are not compatible with safe and just Earth system boundaries.

Many questions remain when it comes to positive tipping dynamics in food system transformation: How can the potential trade-offs between social, economic and environmental goals for food system transformation be reduced and synergies leveraged? Which specific goals should be prioritised to minimise these trade-offs and accelerate food system transformation? And what are the most promising leverage points to take advantage of these synergies across different regions of the world to enable positive tipping points in line with these goals? Tackling this major challenge is only possible when taking a holistic systems-thinking approach that accounts for the different elements in the food system rather than focusing only on agricultural production or food consumption (Poore and Nemecek, 2018; Gaupp, 2020).

Here we outline overarching priority goals for food system transformation in line with the SDGs, Paris Agreement and Biodiversity Agreement, and discuss historic and ongoing tipping dynamics in food system transformation with illustrative case studies. These goals are based on **avoiding** unnecessary GHG emissions and biodiversity loss by reducing food loss and waste; **shifting** to more plant-based diets and agro-ecological farming practices that enable farmland to store more carbon, support more biodiversity and provide other ecosystem services; and **improving** the availability of plant-based and other sustainable protein sources. These targets should thus be key priorities for decision makers (Lee et al., 2019; Frank et al., 2021).

4.3.3.2 Avoiding food loss and waste

Avoiding the emissions and environmental degradation associated with food loss and waste along the entire supply chain represents a key lever in global food system transformation. About one third of all the food produced worldwide for human consumption is lost or wasted annually (Pharo et al., 2021; Mokrane et al., 2023); 14 per cent after the harvest and before it gets to retail (FAO, 2019), and 17 per cent percent at retail, in food-service and by consumers (UNEP, 2021).

If food loss and waste were a country, it would be the world's third-biggest greenhouse gas emitter, after the US and China, responsible for 8 per cent of global anthropogenic greenhouse gas emissions.

(Food and Agriculture Organization of the United Nations, 2015, Melchior and Garot, 2019; Sethi et al., 2020). Similarly, that lost and wasted food consumes about a quarter of the freshwater used per year in agriculture (Kummu et al., 2012) and makes a major contribution to deforestation, land use change and land degradation. At the same time, food security remains a big problem, threatening 828 million people (World Food Programme, 2022). Halving per capita global food waste at retail and by consumers, and reducing losses in production and supply chains, is a target of the SDGs (United Nations Framework Convention on Climate Change, 2022).

France provides an example of how to successfully address this challenge (Box 4.3.8). A combination of private and public interventions in the country have led to nonlinear reductions in food loss and waste and reinforcing feedback in the form of economies of scale, changed social norms and public opinion, and new coalitions that can enable positive tipping points.

Box 4.3.8: France: Combining private and public interventions to reduce food loss and waste

France's strategy comprises private initiatives by large retailers (e.g. supermarket chain Carrefour, which has a 20 per cent market share) and NGOs (e.g. Phenix), but also a national political pact to fight food waste. This strategy led to nonlinear reductions in food loss and waste, and feedback that can enable positive tipping points.

When it was first introduced in 1998, the national law to fight food waste only included tax incentives for supermarkets that donated food (Corréard, 2023), but since 2016 it has become a regulatory instrument, and supermarkets that fail to donate their food can be penalised. This evolution of the pact was partially made possible by the emergence of various private initiatives between 1998 and 2016, among others Too Good To Go (TGTG) (Corréard, 2023). Novel digital platforms and apps like TGTG have made it easier to connect customers to restaurants and stores that have leftover food (Vo-Thanh et al. 2021). Those platforms have undergone nonlinear adoption and diffusion processes via network effects (Too Good To Go, 2023) and offered economic opportunities to reduce food loss and waste. Research shows that such private initiatives can create positive political feedback by increasing the public salience of the food loss and waste issue and the demand for more stringent public food waste regulation (Fesenfeld, Rudolph, and Bernauer, 2022).

The main objective of the pact is to cut food waste by 50 per cent between 2013 and 2025, implying a five per cent reduction annually and was initially focused on retailers. Although they are only directly responsible for five per cent of food waste, retailers connect production and consumption and thus can have feedback effects in both directions (Albizzati et al., 2019; Schönberger, Styles, and Galvez Martos, 2013). Retailers' central role in the supply chain can therefore be considered a strategic intervention to trigger nonlinear change in the area of food loss and waste reduction. For example, retailers can create reinforcing feedback by altering social norms and behaviours of both consumers and producers, and can create economies of scale for innovations to reduce food loss and waste. In turn, this can also enable favourable conditions for policy change and spillovers across countries.

Overall, France's strategy achieved a rapid reduction in food waste and loss and garnered positive international feedback. For instance, a food waste reduction of 18 per cent was measured at 20 agroindustrial test sites during nine months in 2018 (Agence de la transition écologique [ADEME] 2018). In the distribution sector, a 7,000-ton increase in food donations between 2016 and 2018 was measured by the French Federation of Food Banks (Melchior and Garot, 2019). Moreover, France served as a pioneer in this policy field and had a role model effect on Finland, Sweden, Peru and Malaysia, who all introduced similar policies (Melchior and Garot, 2019).

4.3.3.3 Shifting towards more plant-based diets

Reducing consumption of livestock products is the single most powerful leverage point for shrinking the environmental footprint of agriculture and food systems (including Land use changes). Reducing demand for unsustainable foods, especially in middle- and high-income countries (for example, shifting towards more plant-based diets can have a significant impact on GHG emissions and biodiversity loss, as well as having strong synergies with improving public health.) The planetary health diet (PHD) is one proposal for an idealised reference diet that, if adopted, could feed a global population of 10bn in 2050, would significantly reduce the number of deaths from poor nutrition and would be environmentally sustainable (Willett et al., 2019).

Dietary shifts require changes of normative consumer beliefs and behaviours, agricultural practices and policy. Changes to norms are nonlinear and dynamic – the more people who subscribe to a belief or behaviour, the more norms become visible and the more attractive the behaviour becomes to subsequent subscribers, creating a positive feedback loop (Figure 4.3.10) (Sparkman and Walton, 2017). Current norms in many countries hold that eating meat is tasty, ethical and normal. However, there are signs of changing beliefs (Dagevos and Voordouw, 2013). For instance, from 2008 to 2019 the UK has seen a 17 per cent decrease in meat consumption and worldwide participation in 'Veganuary' rose from just 1,280 in 2015 to 628,000 in 2022 (Veganuary, 2022).

Agency – the belief that an individual's change in dietary preferences will make a difference on a global scale and might encourage others to do so as well – is another element that can accelerate this change (Gaupp, Constantino, and Pereira, 2023). This belief may be driven by intrinsic motivation to try new, healthier food choices or a moral obligation to reduce animal suffering and/or environmental impacts, but can also be affected and amplified by socio-economic factors such as the influence of peers or exposure to media and information campaigns that advertise healthy eating. The non-linear spread of the GemüseAckerdemie, a non-profit organisation that focuses on establishing school gardens, fostering cooking skills, and dietary shifts in schools around Germany, Austria and Switzerland is an example for creating such reinforcing feedbacks. This rapidly growing project diffuses social norms, sustainable food knowledge, gardening and cooking capacities among children, parents and cooks in the schools and beyond.

Experimental evidence shows norm changes can be accelerated by targeted nudging interventions, in which public procurement can play a powerful role. For example, a 2017 study of choice-architecture interventions examined the effect of increased availability of vegetarian meals in public cafeterias (Garnett et al., 2019). The study showed that increasing the proportion of vegetarian meals to 50 per cent of all meals offered across a number of trial cafeterias increased vegetarian sales by 40.8 per cent to 78.8 per cent. Moreover, the experiment had little effect on total sales and profit and therefore was an economically viable option for businesses.

The dampening feedback of habitual food choices can be disrupted by choice-architecture interventions, while informational cascades and social contagion of norms work to reinforce willingness to try alternative, more sustainable diets. This works in synergy with the improvement of the alternative protein market, through feedback mechanisms such as economies of scale and learning by doing. In China and the US, a recent study shows that positive user experience is the most important predictor of an individual's intentions to reduce meat consumption and support meat-reduction policies (Fesenfeld et al., 2023), but that this choice was also affected both by social norms and exposure to information.

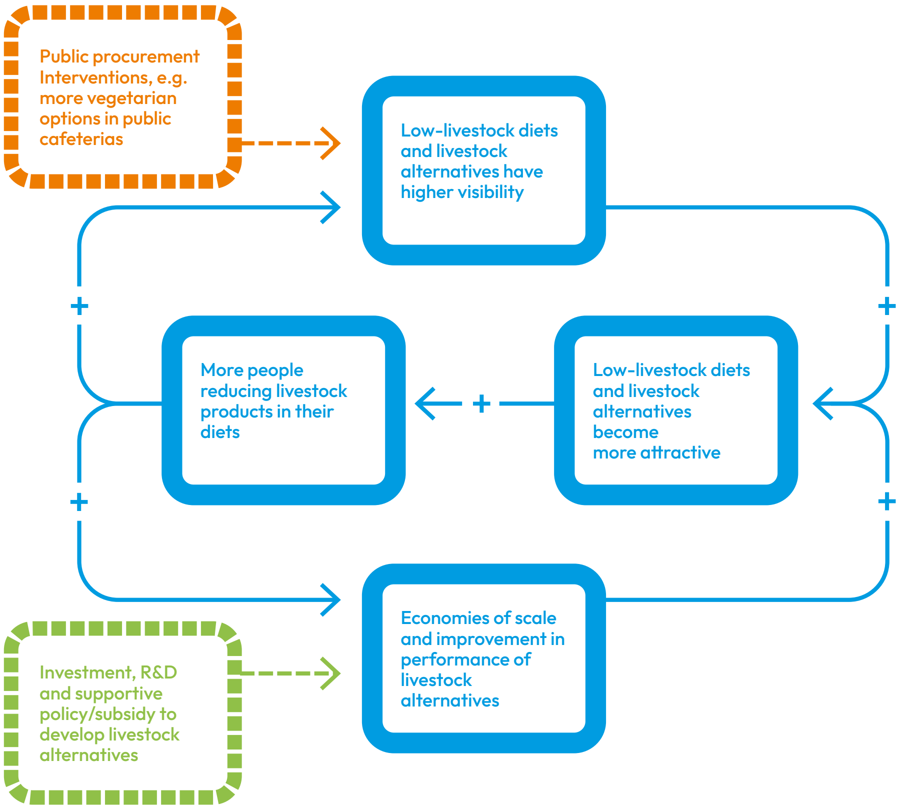

Figure 4.3.10: Positive feedbacks can drive changes in dietary norms, both through social feedbacks that drive consumer beliefs and behaviours (above), and through increasing returns to adoption which drive improvements and economies of scale in livestock alternatives (below), making them more attractive and affordable. These feedbacks can amplify one another. Examples are given of interventions that can strengthen these feedbacks.

4.3.3.4 Improving alternatives to animal products

Alternatives to animal products, such as plant-based, fermentation, or cultivated meat substitutes, can help accelerate dietary shift as they provide a (partial) substitution of meat and dairy in forms that are more familiar to consumers (Ritchie, Reay, and Higgins, 2018). In a report on UK and European meat and dairy alternatives, three key barriers to change were highlighted: high prices, unsatisfactory user experiences and limited availability (Geijer, 2020).

Price parity is an important factor of the uptake of meat and dairy alternatives. Animal products and feed still receive substantially more subsidies in many countries (Vallone et al., 2023; Good Food Institute, 2022). Despite differences in subsidies, large retailers, like Lidl, start to announce price parity between meat alternatives and animal products (Vegconomist 2023).

The UK leads in Europe for price parity and subsequently has the highest purchase and consumption rates of alternatives to meat and milk. Feedback mechanisms contributing to price parity (Figure 4.3.10), such as economies of scale and learning, are evident in the increase of sales and investment over the past 10 years. In the UK and EU, sales of meat substitute products increased from €625m- €1381m (2010-2019), and globally investment in plant-based companies has increased nonlinearly from $23m to $2.1bn (2010-2020). In the US, the meat substitute market has grown exponentially, growing by 54 per cent between 2018 and 2021, an increase in growth rates that was three times faster than that of animal-based products, and plant-based alternatives were expected to reach price-parity soon (Meldrum et al., 2023). Such market developments also create positive feedback in technological learning and investments, which further decrease prices, and signal to retailers, consumers and policymakers a dynamic change. This can create new norms and interest group coalitions.

Targeted policy support, such as the Danish Fund for Plant-based Foods (Good Food Institute, 2021) and procurement standards for public cafeterias, can further accelerate shifts towards sustainable diets (Fesenfeld, 2023; The Food and Land Use Coalition, 2021) and create cross-sectoral spillovers (Meldrum et al, 2023). Promoting a combination of innovations along the supply-chain, such as agri-photovoltaics and alternative proteins, cannot only accelerate technology diffusion but also positively affect acceptance among potential transition losers such as . feed producers by offering them new income sources (Box 4.3.9). Transparency criteria of ecological and health impacts of alternative proteins can foster innovation in and the growth of healthy and sustainable products. Such innovation-oriented and green-industrial policies can lead to economies of scale by fostering technological learning, rapid reduction in costs of clean alternatives, and improvement in their performance (Fesenfeld, 2023; Barrett et al., 2020; Herrero et al., 2020). In turn, this can generate nonlinear political, economic and social feedback dynamics that can accelerate transition (Fesenfeld et al., 2022; The Food and Land Use Coalition, 2021).

Deliberative and participatory governance approaches, such as the German Commission on the Future of Agriculture or the Swiss Citizens' Assembly on Food Policy, can support the design and implementation of such policies to foster dietary shifts (Fesenfeld, Candle, and Gaupp, 2023). The large support of stakeholder groups and representative citizen samples can help to indicate that there is more room for political actions to alter diets than often assumed. For instance, the German Commission on the Future of Agriculture, composed of the central stakeholder groups in German food policymaking across the supply chain, supported policies to internalise the external costs of food products, alter food taxes, subsidies and change public procurement rules to shift towards a planetary health diet. It also highlighted that dietary changes will affect businesses in livestock farming and that respective restructuring in the sector requires cost compensation and planning certainty that is enshrined in law. In the Swiss Citizens' Assembly on Food Policy, a randomly selected, representative sample of 100 people discussed different options to transform the food system in line with the SDGs and produced recommendations for more sustainable food policy (SDSN, 2022). For example, they recommended adopting a carbon tax on climate-damaging food products and altering public procurement rules to foster sustainable diets.

4.3.3.5 Shifting farming practice

A shift in methods of agricultural production is needed to drive positive social, economic and environmental outcomes for farming (Pharo et al.,2019) and increase the resilience of food production to climate change and other shocks (UNFCCC, 2022). The current agrifood system's dependence on a small number of monoculture crops with high chemical inputs, GHG emissions and freshwater use are central to its impacts on the Earth system. Half of the world's habitable land is used for agriculture (OWD, 2019); thus the methods used to manage this land and ensure its productivity have global impacts.

Land-based CO_2 removal, including in agroecosystems, offers huge potential for climate mitigation. The '4 per 1,000' initiative aims to increase carbon storage in topsoils by 0.4 per cent per year globally, with the aim of offsetting a significant portion of anthropogenic GHG emissions. Both the Breakthrough Agenda (IEA, IRENA, and UNFCCC, 2022a) and the Sharm-el-Sheikh Adaptation Agenda (UNFCCC, 2022) set transformation of agriculture as a key priority and target for climate finance, with the combined aim of making climate-resilient, sustainable agriculture the most attractive and widely adopted option for farmers everywhere by 2030.

Development and adoption of a suite of agro-ecological or 'regenerative' farming practices are central to these goals, along with innovation for precision agriculture. These usually emphasise reduced tillage, crop rotation, integrated crop and livestock management and incorporation of perennial crops and trees into farming systems. Agro-ecological farming aims to restore soil health and increase agrobiodiversity and ecosystem service provision, including carbon sequestration, while reducing chemical inputs via increased nutrient recycling and precision application.

A transition to sustainable and resilient farming practices is relevant at all scales and regions (boxes 4.3.9 and 4.3.10), but the urgency is particularly acute for smallholder and subsistence farmers to adapt to increasing climate vulnerability and food insecurity. Hundreds of millions of smallholder farmers are increasingly vulnerable to climate change and are approaching the limits of adaptation for the models of farming on which their livelihoods depend (Morton, 2007). For many subsistence farmers, current Green Revolution farming practices come with costly dependence on chemical inputs like fertilisers and pesticides, or irrigation systems. Often overuse of fertilisers in these farms has caused soil degradation, and reduced water quality and biodiversity. This can drive a vicious cycle of degrading reinforcing feedbacks, where farmers are locked in a cycle of increasing input requirements, increasing indebtedness, and decreasing productivity (The Food and Land Use Coalition, 2021). Accelerating a transition therefore requires breaking this cycle of feedbacks, and strengthening positive feedbacks associated with agro-ecological health and farmer livelihoods.

In Sub-Saharan Africa, around 80 per cent of farms are subsistence smallholdings of less than one hectare (OECD, 2016), operating on degraded land and with minimal capital assets. In this region alone, 50 per cent adoption of regenerative agriculture could lead to a 30 per cent reduction of soil erosion, 60 per cent increase in water infiltration, >20 per cent increase in soil nitrogen and 20 per cent increase in soil carbon, adding ~$70bn gross value per year for farmers. Similar benefits are already driving widespread adoption of regenerative agriculture in both East Africa and areas of India, including certain practices being mandated at state level in Sikkim and Andhra Pradesh (The Food and Land Use Coalition, 2021).

Smallholder farmers have strong social networks which encourage social contagion, and small individual farm sizes which can foster high learning rates. This makes them strong candidates for driving a tipping point in farming practices.

To enable widespread adoption, regenerative farming practices must:

- Offer a more economically attractive livelihood for small-scale farmers (i.e. by reducing inputs or labour costs or through access to subsidies or other incentives).
- Perform better than current practices, through higher yielding or more diverse, nutritious or resilient crops.
- Become a part of prevailing cultural and social norms.

Farmers must also be able to access:

- Markets for crops produced with regenerative methods.
- Information and knowledge networks that enable them to assess the benefits of shifting, and support them to learn new farming practices.

Access to finance can incentivise practices that increase productivity and resilience while reducing emissions and protecting natural habitats (IEA, IRENA, and UNFCCC 2022); as such the Breakthrough Agenda recommends that access to international climate finance by smallholder farmers needs to sharply increase (Meldrum et al., 2023). Multiple mechanisms exist for this, but one model already driving innovation is the Voluntary Carbon Market (VCM). Through established monitoring protocols and verification standards, carbon sequestered in biomass and soils can be accredited and sold on an open market to buyers looking to offset carbon emissions. Payment for carbon credits can help to fulfil the enabling conditions above by offering farmers incentive payments or access to markets for a ‘virtual’ carbon crop in addition to conventional crops, helping them to build diversified and more resilient livelihoods (Box 4.3.9). Globally, VCMs have been growing exponentially, at a compound annual rate of over 30 per cent from 2016-2021 (World Bank, 2022), with the value of carbon credit retirements close to US$1bn and expected to grow to 15 times that by 2030. Recent developments have questioned the credibility of credits generated through ‘reduced deforestation’, which are qualitatively different from credits produced via actively sequestering carbon in vegetation or soils (Balmford et al., 2023). This has served to increase demand for credits based on sequestration, and those with demonstrable social co-benefits.

In countries where industrial agriculture predominates, similar mechanisms for paying land managers for provision and improvement of ecosystem services remain an effective tool. In these systems, high levels of subsidy have considerable influence over the structure of farm business models and the choices available for land management. Diversifying income streams is often attractive for farmers as it offers resilience in the face of marginal livelihoods and volatile markets (Box 4.3.10). Research in the UK suggests that, given incentive structures that make agro-ecological practices economically viable, and confidence in long-term government commitment to agri-environmental policies, farmers are prepared to shift practice accordingly (Guilbert et al., 2022). However, powerful dampening feedbacks also exist in the agro-industrial sector (Daugbjerg, 2011), and it is not clear whether potential for tipping dynamics exist, as opposed to linear change.

Box 4.3.9: Voluntary carbon markets drive agroforestry adoption in East Africa and India

The International Small Group and Tree Planting Programme (TIST) supports access to voluntary carbon markets to incentivise tree planting by smallholder farmers in Kenya, Uganda, Tanzania and India, with the goal of maximising benefits for participating farmers (TIST Program, 2023). Since its inception in 1999, it has grown rapidly through a mixture of grassroots activity, social contagion and targeted expansion (Emmanuel O. Benjamin and Blum, 2015), to include more than 170,000 participants (TIST Program, 2023). TIST members have planted more than 23m trees and own the rights to verified carbon credits generated by measuring their growth. Small incentive payments are made until trees are large enough to qualify for carbon credit verification, and these appear sufficient to offset the opportunity cost of committing to tree planting (Emmanuel O. Benjamin and Sauer, 2018).

Once planted, trees provide multiple co-benefits to farmers (De Giusti, Kristjanson, and Rufino, 2019) including fuelwood, animal fodder, fruit or nut crops, shade, and soil stabilisation. These benefits generate strong social-ecological reinforcing feedbacks, providing motivation for trees to be maintained over many years. The greening impact of TIST tree-planting is visible at landscape scales, and can be seen to extend beyond individual tree-groves to neighbouring land (Buxton et al., 2021), potentially strengthening these feedbacks. Regular meetings, training and visits by extension officers to measure tree-growth ensure accountability and transparency, and generate strong social feedbacks.

TIST's organisational structure is inherently scalable, and designed to facilitate sharing experience, information and training, both vertically and horizontally. Coupled with a culture of learning by doing, this means that best practices and innovations, including for other regenerative farming practices, can be spread rapidly (Masiga, Yankel, and Iberre, 2012). Rotating leadership throughout the programme structure, with equal leadership for women and men, facilitates social capital which further enhances the programme outcomes (Marshall, 2022), including ensuring economic empowerment for participants (both male and female) (Emmanuel O Benjamin, Ola, and Buchenrieder, 2018) which in turn enables greater investment in farming, education and health (Benjamin, Blum, and Punt, 2016), bringing further benefits aligned with multiple SDGs (OECD, 2020).

Growth in African-origin carbon credits slightly exceeds the global average growth rate in VCMs, with credits based on agriculture, soil sequestration, forestry and land use attracting the highest prices (two to four times the global average) (ACMI report). However, it is estimated that Africa currently generates only ~2 per cent of its annual potential for carbon credits, with potential to generate around US$50bn by 2030. This represents a powerful opportunity to leverage the feedbacks demonstrated in TIST and other programmes.

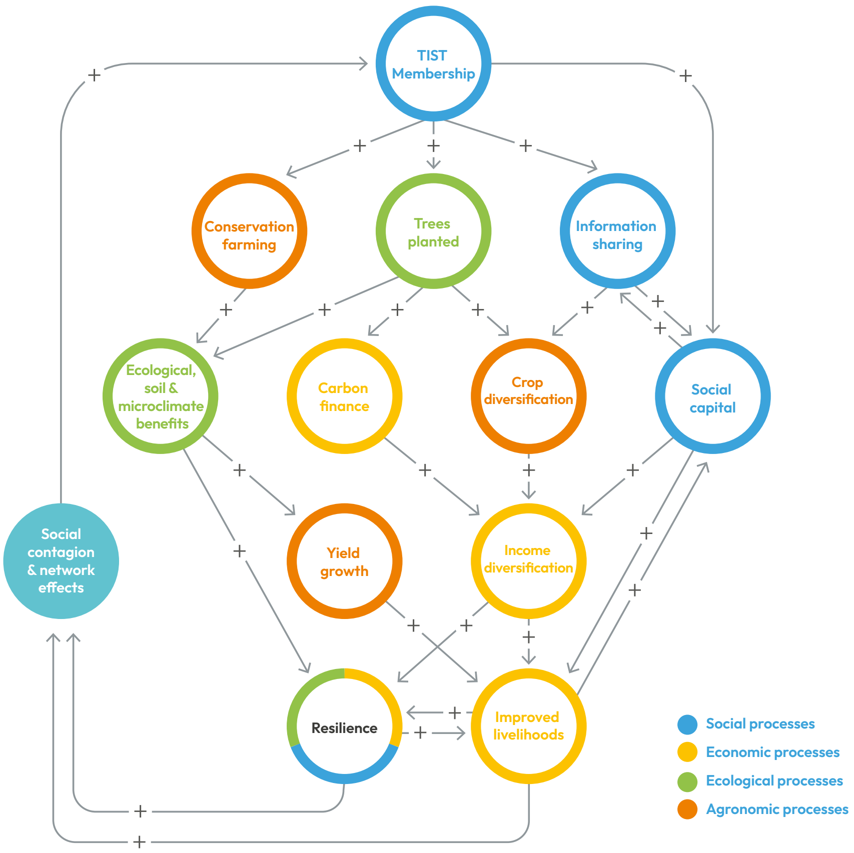

Figure 4.3.11: Positive feedbacks initiated by the TIST programme that increase capability of farmers, support them to access and benefit from voluntary carbon markets and improve the performance of their farms relative to the vicious cycle of degradation and vulnerability presented by the status quo.

4.3.3.6 Food system tipping points have important feedbacks for protecting nature

Together, widespread adoption of sustainable diets, the reduction of food loss and waste, and the sustainable use of land can work in synergy with one another to reduce GHG emissions, especially methane, and meet SDG targets for food security and sustainable livelihoods (Figure 4.3.9). Critically, they also have powerful synergies for protecting nature, including critically vulnerable carbon sinks and biodiversity hotspots like the Amazon.

Both reducing food loss and waste and changing towards planetary health diets can significantly reduce the global land area required for food production, despite growing populations, and open opportunities for nature recovery, including land-based CO_2 removal (Powell and Lenton, 2012; Meldrum et al, 2023). This could help reduce focus on maximising yields in intensive agriculture, and open opportunities to **shift** farming practice through incentives for diversifying farm business models to include ecosystem service provision, with the aim of restoring ecological health and function to agrifood systems.

Growing markets for natural capital and payments for ecosystem services, supported by strong policy and incentive frameworks to support agro-ecological farming and nature-based solutions, can make alternative models of land-management economically viable by creating economies of scale, and weaken economic incentives for environmentally degrading practices, including intensive livestock production. The rapid growth in voluntary carbon markets globally (close to US$1bn in 2021) demonstrates this potential, and these and other natural capital markets are seen as key pathways for directing climate finance, with significant recent commitments made by the EU (EU Parliament, 2023) and African leaders (Nairobi declaration, 2023). Recently, important critiques have been made of the transparency and effectiveness of credits for **avoided** emissions (e.g. West et al., 2023), and warnings of the risks of inappropriate (e.g. tree planting in African grasslands) (Bond et al., 2019) or poorly implemented carbon removal initiatives. These are undermining confidence in carbon markets and present a critical incentive for the evolution of more robust, transparent and accountable mechanisms to direct finance to appropriate solutions. Key to this is also ensuring benefits from these markets are accessible to communities and Indigenous peoples, who are key to ensuring sustainable land use transitions in much of the world. Reducing deforestation and supporting regeneration of natural vegetation can reduce annual net GHG emissions by more than 5GtCO2e by 2030, and more than 8GtCO2e by 2050, while contributing to halting and reversing biodiversity decline, and all while delivering a possible net economic gain of US$895bn per year by 2030, and US$1.3tn per year by 2050 (The Food and Land Use Coalition, 2021).

Shifts in values and norms which can accelerate tipping towards planetary health diets are also likely to be tightly linked, and therefore mutually reinforcing, to those which build demand for 'deforestation-free' products or which can demonstrate strong credentials for supporting conservation and Indigenous rights. These shifts can be accelerated by development of robust and transparent mechanisms for verifying and labelling provenance, and further strengthened by public and private-sector commitments to deforestation-free supply chains (The Food and Land Use Coalition, 2021).

4.3.3.7 Strategic interventions to enable positive tipping points in food systems

Box 4.3.10: Embracing new technologies and compensation schemes to support farmers and incentivize shifts towards more plant-based food and 'regenerative' farming.

Current subsidies in many countries, such as in the EU and US, incentivise farmers to not embrace regenerative farming practices and produce animal products and feed rather than plant-based food for human consumption. (Vallone et al, 2023). While demand-side shifts and clear market signals are an important lever for shifting towards more plant-based food production, it is important to incentivise and support farmers in shifting towards more plant-based food production. For example, targeted innovation policies could support the scaling of agri-photovoltaics in combination with the production of plant-based food to offer farmers a new income source when shifting their business model from feed or animal products towards plant-based food production (Fesenfeld et al., 2022).

Innovation and rapid reductions in the costs of such new technologies at the nexus of the energy and food systems can also help to reduce climate adaptation costs for farmers by protecting plants against extreme weather events. Moreover, in some regions and for some crops, new technologies such as agri-photovoltaics can increase overall land productivity by up to 70 per cent (Weselek et al., 2019; Tormer and Aschemann-Witzel, 2023). Other technologies, such as smart and precision-farming tools, can also reduce the costs and environmental burden of plant-based food production and thus help farmers to shift production (Finger et al., 2019; Walter et al., 2017; Finger, 2023). Here, targeted financial support and on-the-ground consultancy are important to foster the uptake and diffusion of such technologies. Focusing on farmers that act as important nodes in social networks and regions can be very effective to foster social contagion and innovation diffusion.

Novel satellite and result-based payment schemes can substantially reduce the administrative burden for farmers and thus resistance to more environmentally friendly and plant-based food production methods. Rapid improvements and economies of scale in digital farming technologies and high-resolution remote-sensing technologies thus offer new opportunities for accelerating transformation towards more sustainable farming methods, such as agroforestry (Teraski Hart et al.,2023). Moreover, the use of bio-char or other carbon-sequestering practices in plant-based food production and the potential integration into carbon markets can offer new income to farmers and increase their production resilience, and thus lower their risks when switching towards plant-based food production.

Targeted compensation schemes, especially designed to switch production of large feed and animal product producers with high environmental footprints, are another important measure to reduce resistance against production shifts towards plant-based food and regenerative farming. Focusing incentives for production-shift, emission-pricing (e.g. nitrogen surplus fee, methane emission trading), phase-out and compensation schemes on large producers in key regions (e.g. regions and farms with excessive nitrogen pollution or organic soils) is particularly promising because it reduces the number of affected farmers, can facilitate the negotiation process between farmers and governments, foster network effects and create positive political feedback (e.g. reduce backlash from smaller, unaffected farms). Using new revenues from emission pricing to support most affected regions and low-income groups (e.g., via reduce VAT rates on plant-based food), foster innovation, and create alternative income sources can reduce opposition. This can open a window of opportunity for more fundamental changes in agricultural subsidies that are also needed for accelerated food system transformation.

Box 4.3.11: Packaging and sequencing policies along the supply chain that focus on transformation opportunities: The example of the Danish Plant-based Fund

Importantly, production-focused policies that target farmers (Box 4.3.10) should be smartly combined and sequenced with policies along the entire supply chain that foster demand-side shifts and provide a clear signal for a growing plant-based food market. Such measures can include public procurement standards, innovation subsidies for the development and scaling of alternatives to animal products, and nudges in supermarkets and restaurants, but also consumer-sided price instruments such as tax reductions on plant-based foods or new pricing instruments for emission-intensive food products. The combination and sequencing of different policies not only increases the effectiveness but also the feasibility of policy change, by creating enabling conditions (e.g. shifting social norms and increasing public support for transformative policies) and reinforcing feedback (e.g. creating economies of scale in plant-based and alternative protein supply chains) (Fesenfeld et al., 2022).

The Danish Plant-based Fund is an example of a recent policy change that takes a packaging approach and integrates measures along the supply chain by focusing on the opportunities of food system transformation. The new policy involves funds for plant-based food product development and marketing, plant-based eco-schemes that pay premiums to farmers who grow plant protein crops for human consumption. A programme to promote environmental technologies targeting innovations in plant-based food-processing facilities and a strategy and projects to develop 'green proteins', particularly proteins produced from fermentation and cultured meat. It also includes an action plan to promote plant-based foods and dietary shifts (e.g. via nudging in public canteens, restaurants, supermarkets, etc). Importantly, the establishment of the fund involved deliberation among key (partially opposing) stakeholder groups, such as environmental NGOs and farmer associations, and inputs from scientists focusing stakeholders' attention on the opportunities of shifts towards plant-based food.

This strategic approach to policy design and framing might function as a best-practice case and be diffused to other countries and regions to create the enabling conditions (e.g. norm shifts and increased support) and reinforcing feedbacks (e.g. economies of scale) to accelerate food system transformation.

These examples show that positive tipping points in food and land use systems are possible, but that they are rarely a 'manna from heaven' and need an enabling environment and strategic decision making in politics, civil society and business. Decision makers need to take care of unintended negative effects and strategically design interventions to enable positive tipping. Based on existing scientific synthesis work (Fesenfeld, 2023, Fesenfeld et al., 2023; SAPEA, 2023; Galli et al., 2020; The Food and Land Use Coalition, 2021) we propose key interventions that can help to create enabling conditions for positive tipping points in food systems (Fesenfeld, Candle, and Gaupp, 2023):

1. **Strengthening adaptive and deliberative food system governance**
   Expanding beyond a narrow agricultural policy framework to encompass a comprehensive food system governance approach presents avenues for the involvement of new stakeholders and the potential to create reinforcing feedback via belief-updating and information cascades. This is particularly the case as, from a food system rather than a pure agricultural policy perspective, new actors enter the policymaking space, form novel coalitions and exchange information. Embracing inclusive and deliberative governance approaches, such as food policy councils and citizens' assemblies, at the regional, national and international levels can support such feedback and increase the input and output legitimacy of more ambitious policy change, such as **avoid measures** related to a fundamental repurposing of agricultural subsidies and new emission prices. Engaging diverse stakeholders in joint scenario development and multilateral negotiation processes can overcome political and implementation hurdles of such policy change by offering room for negotiating more integrated policy packages that compensate losers and open new business opportunities.

   a. **Strengthening the food system science-policy interface and science-based targets**
      Strengthening the knowledge and capacities of stakeholders is important for creating reinforcing feedback such as changes in norms and the creation of economies of scale. For an improved science-policy interface, several key actions can be taken:

   b. **Integrate research and data from various disciplines and sectors**, such as agriculture, food consumption, ecology, justice, food security and health, spanning different parts and levels of the food system.

   c. **Assess and provide knowledge in a transparent and independent manner**, ensuring credibility and reliability. Furthermore, independent policy progress monitoring can also create the enabling conditions for sudden policy changes (e.g. the UK Climate Change Committee (Carter and Jacobs, 2014).

2. **Develop science-based targets for policymakers and other key stakeholders** (e.g. businesses) can help to diffuse norms and trigger accelerated action. The nonlinear spread and adoption rate of the science-based target initiative is an example of how improved science-policy interfaces can lead to reinforcing feedback (Ramdorai, Delivanis, and Simons 2023).

3. **Strengthening policy sequencing, policy packaging and framing**
   Public and private decision makers can strategically combine policy framing, sequencing and packaging to create positive feedback loops and overcome political, social, technological and economic barriers to food system transformation (Fesenfeld, 2023). This positive political feedback can enable policies aimed at decline-oriented reforms, such as fundamental changes to existing non-sustainable subsidies, or the implementation of emission pricing schemes. In order to ensure a just and feasible transition, policy packaging becomes crucial to increase policy effectiveness and potentially compensate those adversely affected by the transition (SAPEA, 2023; Fesenfeld et al., 2020). This can increase fairness and facilitate broader stakeholder and public support.

   Initiatives by private companies (as outlined in the case studies above) can also lead to nonlinear changes and feedback to public policies. Framing policies around plant-based foods (rather than meat) and the opportunities of transformation (e.g. the Danish Plant-based Fund) can reduce political backlash. Moreover, policies adopted in one country can create spillovers to other jurisdictions and create positive feedback loops in these contexts (see examples of French Food Waste Legislation above). To increase the likelihood of such cascading effects, policymakers at the local, national, and international levels should engage in policy experimentation, which facilitates learning, feedback and diffusion.

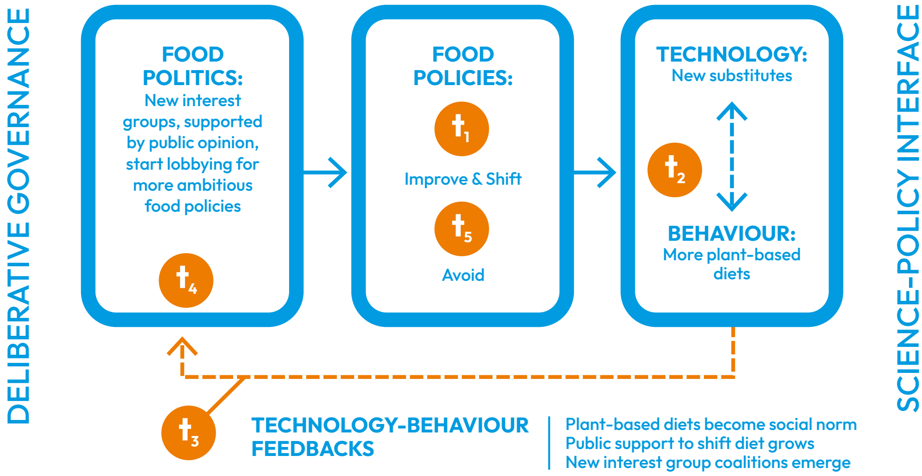

Figure 4.3.12: It is crucial to create the enabling conditions and reinforcing feedbacks to accelerate food system transformation by taking a systemic perspective and focusing on the opportunities for change. Building on examples like the Danish Plant-based Fund (Box 4.3.11) illustrates how the strengthening of deliberative governance, science-policy interface and strategic policy sequencing, design and framing can create the enabling conditions (e.g. changes in social networks, norms, product accessibility, quality and price) and lead to reinforcing technology-behaviour feedback (e.g. economies of scale, social contagion, information cascades) that reduce barriers for triggering positive tipping points. For example, deliberative forms of governance and stakeholder exchange focusing on the opportunities of change can enable in t1 (first phase) the adoption of improve and shift-oriented policies, such as the Danish Plant-based Fund. In t2 (second phase), such policies can then foster innovations and positive synergies between technological change (e.g. in meat substitutes) and behavioural change (e.g. supporting dietary change in cafeterias). Strengthening the science-policy interface can enhance policy impact and accelerate such technology-behaviour changes. In t3 (third phase), technological-behaviour changes can lead to reinforcing feedback, e.g. altering social norms, public opinion and interest group coalitions. In t4 (fourth phase), this can create the enabling conditions for changes in food politics and enable in t5 (fifth phase) the adoption of more ambitious avoid measures (e.g. new emission pricing instruments) that can trigger positive tipping points. The figure is based on (Fesenfeld et al., (2022)).

Chapter 4.4 Cross-cutting enablers of positive tipping points

4.4.1 Socio-behavioural systems

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Summary

This chapter explores changes in socio-behavioural systems that provide important enabling factors and feedbacks for the positive tipping points described across Section 4. In addition, socio-behavioural systems can themselves be tipped, usually driven by complex contagion processes along extended social networks. Changes in social norms are often key drivers for social-behavioural systems, as they define acceptable behaviour, both in consumption domain and in the civic and political domains. Social movements are the main actors, seeding complex contagion of new social norms. However, social movements rely on allies and sympathisers for complex contagion to spread across social networks. Policymakers can also help to establish new social norms through policies that favour behaviours prescribed by new social norms. The chapter also describes the role that education can play in empowering actors to become agents of change.

Key messages

- Changes in socio-behavioural systems often precede and fuel political and technical changes and can exhibit tipping dynamics through social contagion processes.
- Social movements can initiate tipping in social-behavioural systems by shifting social norms, but to be successful they need an extended network of allies and sympathisers.
- New social norms that could beneficially transform society include anti-fossil fuel norms and sufficiency norms. However, replacing deeply entrenched values and norms around consumerism in favour of sustainable sufficiency would be extremely difficult.

Recommendations

- Accelerate the spread of desired new norms and behaviours through coordinated policies such as fossil-fuel phase-out, post-carbon infrastructure investment and policies that make desired behaviours the most affordable, visible and convenient option.
- Provide 'free social spaces' for social movements to gestate, and for members of such movements to build their networks and learn from each other.
- Equip social actors to become effective seeders of social contagion of new social norms through enhanced capability and efficacy.

4.4.1.1 Introduction

Social and behavioural change are key forces that can drive social tipping. Socio-behavioural systems encompass social norms, behaviours and lifestyles, communities and their cultures, and institutions. More than 65 per cent of global GHG emissions come directly or indirectly from household consumption (Ivanova et al., 2016). According to the IPCC, demand-side mitigation could reduce the total GHG emissions by 40-70 per cent compared to the baseline scenario emissions by 2050 (Creutzig et al., 2022). Demand-side mitigation (see Chapter 4.3) refers to changes in technology choices, consumption, behaviour, lifestyles, coupled production-consumption infrastructures and service provision (Creutzig et al., 2018).

A host of consumer behaviours have significant environmental impacts – for example, mobility choices, including decisions about whether and how often to fly; food waste; diet; and home weatherisation and electrification. However, there are other socio-behavioural changes with the potential to be highly impactful. Civic and political actions, including voting behaviours but also participation in social movements and boycotts, can have large impacts through their effects on policy and politics (4.4.2). Discussing climate change with one's peers can increase their concern about climate change and willingness to support mitigation policies, and potentially contribute to collective action (Geiger and Swim, 2016). Finally, there are also many socially reinforced beliefs that may be important to overcome or replace in order to shift societies towards more sustainable consumption patterns (e.g. consumerism, individualism).

Research has identified the aspects of lifestyles that support limiting global warming to 1.5°C and the required demand-side mitigation measures, see Figure 4.4.1 (Akenji et al., 2021). Addressing carbon inequality is crucial though, with the richest 10 per cent globally accounting for nearly half of all CO_2 emissions, indicating that significant carbon cuts must be made by affluent individuals through measures like carbon budget policies, luxury-focused carbon taxes, and the spread of sufficiency norms, especially among the wealthy (Kenner, 2019; Gössling and Humpe, 2023; Duscha et al., 2018; Rammelt et al., 2022; Oswald et al., 2023, IPCC 2023, Büchs et al., 2023; see Chapter 4.6). Social norms directly affect behaviours and lifestyles by defining what behaviours are appropriate in different contexts. What is considered appropriate is often linked to moral principles – what is considered right or wrong in a society (Buckholtz and Marois, 2012; Nyborg, 2018) – and can vary both across and within societies. People often behave according to social expectations for myriad reasons, including an intrinsic desire to belong and concerns that norm transgressions could lead to social exclusion (Constantino et al., 2022; Schneider and van der Linden, 2023). Changing norms hence translates into behavioural change by denormalising one behaviour and normalising another – e.g. denormalising investing in fossil fuel companies and normalising divestment (4.4.4).

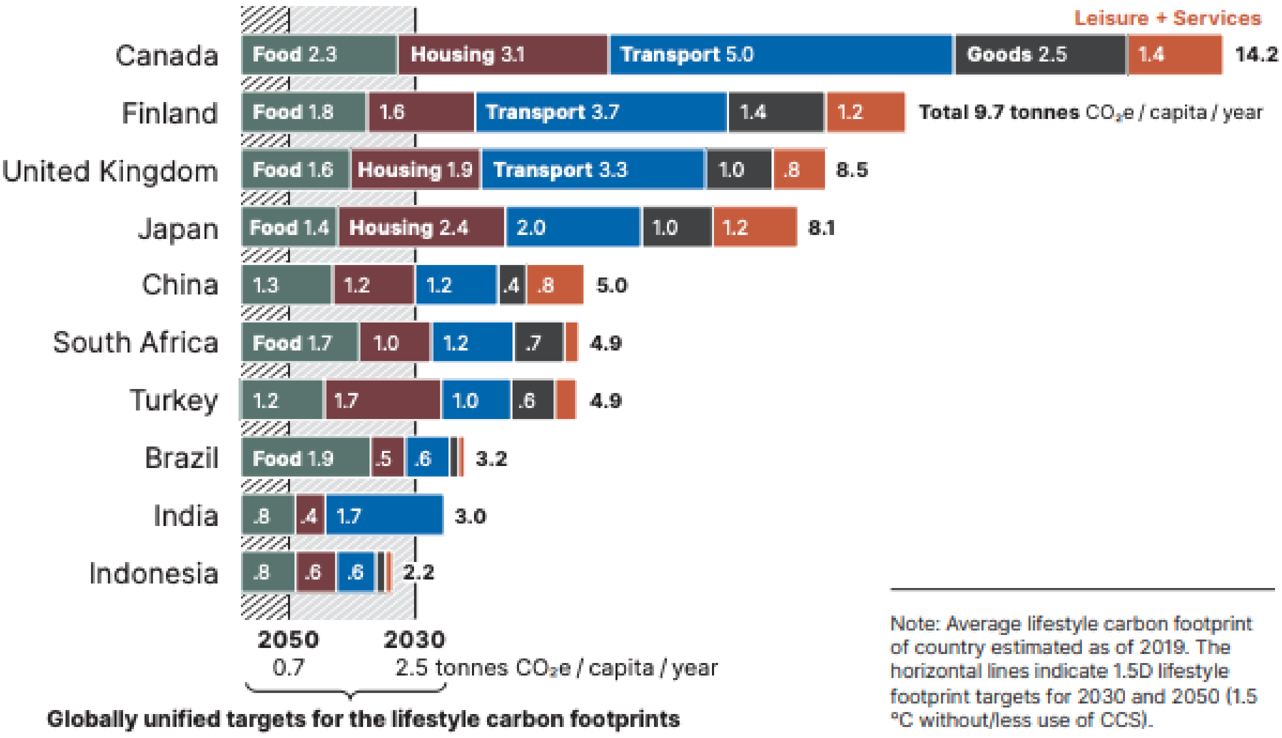

Figure 4.4.1: Per capita average carbon footprint and its breakdown for selected countries Source: Akenji et al., 2021.

4.4.1.2 Social norms facilitate tipping and can themselves tip

Carbon lock-ins depend in part on and reinforce social norms linked with petrocultures (belief systems around entitlement to cheap, abundant energy provided by fossil fuels to feed consumerist lifestyles, see Wilson et al., 2017; Daggett, 2018). Decarbonisation requires disrupting carbon lock-ins and the socio-behavioural foundations that uphold them (Bernstein and Hoffmann, 2018). Such a disruption could come from the large-scale adoption of anti-fossil fuel norms, which convey the inappropriateness of behaviours that require the extraction or consumption of fossil fuels (Green, 2018; Blondeel, 2019). Social norms also affect policies, as they inform which policies are likely to have significant public support. Change in civic and political behaviour facilitates changes in policies, as politicians would be given a clear mandate for decarbonisation and regenerative policies (Stokes, 2015; Willis, 2018; see 4.4.2).

Research suggests that one important element in the social system that can tip are social norms and the behaviours, beliefs and practices they prescribe. Other elements that are important, such as social identities and values, typically change more slowly. New social norms, ideas or behaviours can spread through complex contagion processes across social networks (Guilbeault et al., 2018; Fink et al., 2021; Becken et al., 2021) – i.e. an individual is likely to adopt a new norm, idea or behaviour if a certain number of their peers have adopted it. Complex contagion processes can lead to social tipping (Wiedermann et al., 2020; Xie et al., 2021), including in the context of climate change (Bury et al., 2019). This means the contagion of a new norm, idea or behaviour spreads initially gradually and slowly until a critical threshold (critical number of early adopters) is reached and the contagion becomes self-reinforcing, causing transition of the social system towards a new state (a new norm, behaviour).

Complex contagion is influenced by factors such as similarity of interacting individuals, the resonance of new norms with existing values and norms and the feasibility of prescribed behaviours (Guilbeault et al., 2018; Woodly, 2015; de Lanauze and Siadou-Martin, 2019; Schaumberg and Skowronek, 2022; Nyborg et al., 2016; Kaaronen and Strelkovskii, 2020). Networks characterised by clusters of strong local ties can facilitate and accelerate complex contagion (O'Sullivan et al., 201; Centola et al., 2018).

4.4.1.3 Social movements as norm entrepreneurs

Socio-behavioural change has to begin somewhere. For example, actors committed to an alternative norm or behaviour may be able to seed complex contagion. Social movements and civil society groups can be such initiators, and often have been in the past. For instance, the abolitionist movement was crucial for abolishing slave trade and slavery (Oldfield, 2013).

Social movements create social change by creating new norms, practices or beliefs, denormalising the status quo and bringing particular issues to the attention of the public.

(Nardini et al., 2020; Pathak et al., 2022). Such movements are particularly powerful when they can integrate their identity and the new norm, i.e. when they become the change they want to see in the world (Smith et al., 2014). Climate movements were identified as one among 10 main drivers to achieve (deep) decarbonisation by 2050 by triggering disruptive change through a range of actions, including campaigning, protest, climate litigation, boycotts and civil disobedience (Muñoz et al., 2018; Wasow, 2020; Engels et al., 2023; Nisbett and Spaiser, 2023).

Social movements must strike a balance between publicity and alienating the public, though (Zhou, 2016), as the successful seeding of complex contagion relies on diverse allies, who can reinforce and multiply the messages of the movement, by introducing it to communities lying outside a movement's direct spheres of social influence (Nardini et al., 2020; Nisbett and Spaiser, 2023). Together, social movements and their supportive sympathisers can reach the 'sweet spot' (around 10,000) in scaling social change (Bhowmik et al., 2020) through a ripple effect (Figure 4.4.2).

Some research suggests that the threshold for social movement mobilisation necessary to achieve broader social change can range between 3.5 per cent and 25 per cent of the population (Chenoweth and Stephan, 2011; Centola et al., 2018); however, these estimates have a lot of uncertainty and are likely to be context specific. For example, the research conducted by Chenoweth and Stephan (2011) analysed 323 country cases and found that when at least 3.5 per cent of the population actively participated in non-violent civil disobedience, their political demands were successful. However, none of these cases involved a Western liberal democracy, and all involved regime change, not system-wide transformation to a post-carbon economy.

There is also evidence that mundane features of many societies, such as the diversity of preferences and beliefs, how interdependent the culture is, and whether there are in- and out-group dynamics or strong social identity groups, have implications for whether and how social change spreads through social networks (Ehret et al., 2022; Constantino et al., 2022). Relatedly, a wider, diverse network of allies is often crucial for social movements to take hold.

Generally speaking, social movements emerge and create social change often through individuals with a strong urge to 'change the world', who inspire others around them, creating a vocal minority that can transcend the collective action problem (failure of a group of individuals to achieve common good), particularly when presented with a sufficiently large and certain threat requiring collective response (Ronzoni, 2019; Barrett and Dannenberg, 2014). Through traditional and new digital media, the movement spreads to other locations and communities. Grassroots groups coordinate their activities and actions, building a networked, international social movement with multiple leaders that mobilise key stakeholders and the public (Figure 4.4.2). As we will discuss in 4.4.3, once social movements have successfully mobilised a committed, well-organised minority (activists and allies/sympathisers) around a common cause they can affect political change.

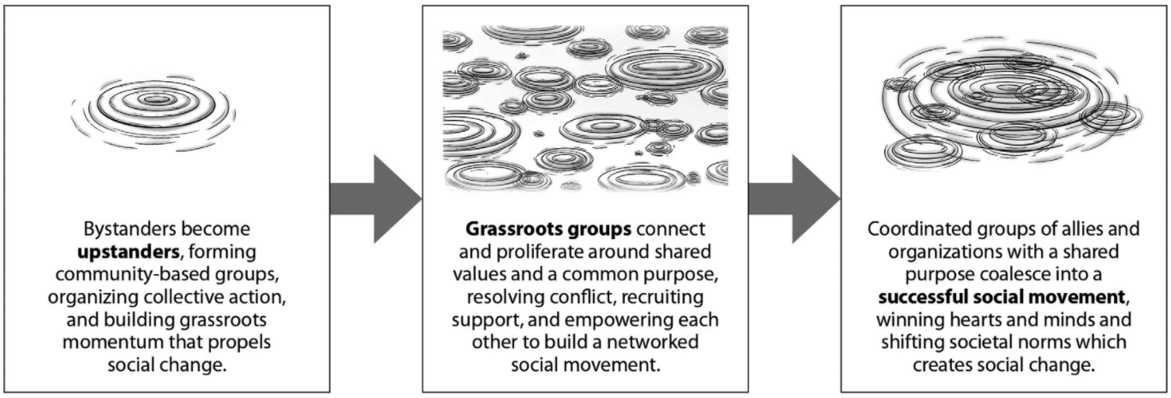

Figure 4.4.2: Ripple effect of social movements (Source: Nardini et al., 2020).

Changes in social norms are often contentious. New norms challenge existing norms and behaviours and the privileges and power structures that underpin them. This inevitably provokes resistance and backlash from those benefiting from existing norms and behaviours (Bloomfield and Scott, 2017), or whose social identities and values are closely aligned with them. It is therefore not surprising that research has identified a surge in denial and climate action delay arguments as well as a backlash against climate movements that challenge business-as-usual (Lamb et al., 2020; Falkenberg et al., 2022; Vowles and Hultman 2022; Nisbett and Spaiser, 2023). As has been noted earlier in this report, forces trying to preserve the current state of the system are likely to increase as we approach a tipping point. Despite the backlash, some new norms, like the anti-fossil fuel norms, have nevertheless been able to gain increasing traction (Harvey, 2023).

4.4.1.4 Policies that facilitate tipping in social norms

For socio-behavioural change, policymakers are also important, as policies can have a great impact on shifting norms, behaviours and practices. For instance, the law banning smoking in closed public spaces has shifted society from a state where most smokers were inconsiderate to non-smokers, to a new equilibrium in which a large share of smokers are considerate, even in unregulated spaces (Nyborg and Rege., 2003). Policymakers can support the propagation of anti-fossil fuel norms by making political decisions that explicitly signal the end of the fossil fuel era, for instance by withdrawing from all oil extraction activities, as Denmark did in 2020, or mandating a ban on petrol/diesel car sales, as the UK did from 2030 (now put back to 2035).

Additionally, governance interventions increase the visibility of certain behaviours and can help to establish emerging norms and the behaviours they prescribe.

Behaviours that are easily observable (e.g. smoking, mask wearing) may be more likely to show tipping dynamics due to the more prominent role of social norms and sanctioning in guiding those behaviours (Nyborg et al., 2016). Policies can explicitly increase visibility of desired behaviours. A study showed that making a behaviour observable tripled compliance, outperforming even cash incentives (Yoeli et al., 2013; Shrum, 2021). Moreover, as far as targeting companies is concerned, regulatory climate shaming (e.g. through rankings, ratings, labelling, company reporting, lists or online databases based on corporate climate performance) can be quite effective. (Yadin, 2023).

Many climate-relevant behaviours are perfectly visible though, such as driving a petrol-fuelled car versus cycling or walking. In such cases, governance interventions must look for ways to break self-fulfilling expectations (Nyborg et al., 2016) – i.e. people need to believe that others will take up cycling or walking and policies can provide reasons for people to change their expectations. Costly public investments, like bicycle lanes, can change expectations about which behaviours are likely to prevail as they signal that incentives (and potentially social norms) have changed for everyone (Nyborg et al., 2016, see 4.3.3). Usually, several social, economic and other feedbacks are present and can dominate to various degrees.

Transitioning to new behaviours is often costly, particularly in terms of upfront costs. Behaviour and lifestyle changes are influenced by norms, but also by perceived and actual action control – i.e. people can only adopt behaviours that are possible and salient (Ajzen and Fishbein, 2005; Fritsche et al., 2018). Hence, if reinforcing social feedbacks (e.g. anti-fossil fuel norms) are present or emerging but dominated by disincentives (e.g. costs), policy can modify the latter through taxes, carbon fees with dividends, subsidies, or infrastructure investments (Nyborg et al., 2016; Stiglitz et al., 2017).

4.4.1.5 The role of climate education and engagement

Strengthening climate education and engagement is another enabling intervention (Otto et al., 2020, see Figure 4.4.3). Since climate issues are complex and deeply intertwined with unsustainable development and cultural change, an education system that facilitates transformative learning processes and fosters collective engagement to enable agency for transformation, is fundamental for triggering PTPs (Macintyre et al., 2018). In the long term, climate action-oriented education can foster empowerment and agency (Stoknes, 2015; Tannenbaum, 2015; Colvin et al., 2019), increasing competence by providing facts and strategies for behavioural change (Hertwig and Grüne-Yanoff, 2017) and instigating sustainable lifestyles and career pathways, widespread engagement and action.

Education can also create rapid changes by connecting school classes with local transformation actors, such as farmers, entrepreneurs and non governmental organisations (NGOs). For example, school farms in the UK are fostering students' engagement with learning while facilitating sustainability practices among local farmers. Such processes create learning feedbacks across students and local transformation actors creating networks of positive tipping agents. Education can thus also enhance self-efficacy or agency for rapid social change by actively engaging students in real-world climate action projects and providing soft skills which translate into collective efficacy for society (Lenton, 2020; 2022; Centola and Macy, 2007;Centola 2018; Törnberg 2018).

A population size of around 10,000 people has been shown to be a 'sweet spot' scale for accelerating social learning between students, parents and peers (Bhowmik et al., 2020). Intervening via education at this scale can trigger social learning through multiple loops and can thus trigger multi-level interactions across formal and informal institutions and state and non-state actors (Pahl-Wostl et al., 2009). And finally, education can promote 'active hope' for young people suffering eco-anxiety and climate trauma by involving them in activities that shape the future they hope for (Macy and Johnstone, 2012). This empowers them to become potential seeders of positive social tipping processes, for example through climate activism.

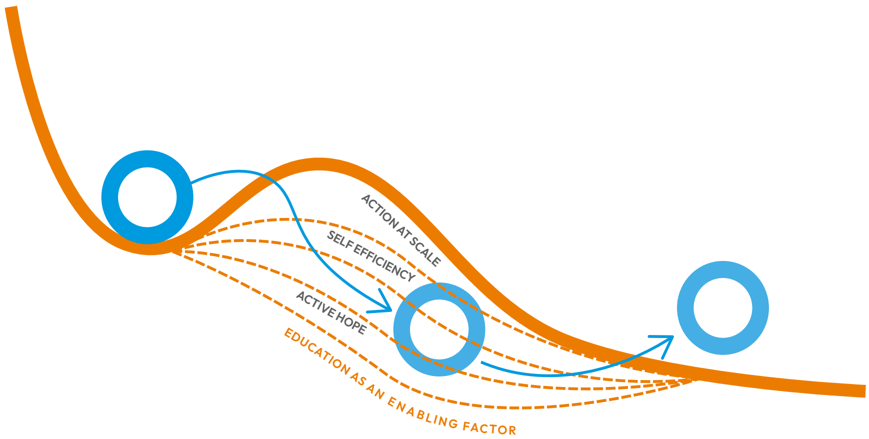

Figure 4.4.3: How education can enable social tipping through triggering action at scale, self efficacy and active hope.

Box 4.4.1: POSITIVE TIPPING POINTS IN INFORMATION AND KNOWLEDGE SYSTEMS

In information and knowledge systems (Cash et al., 2003), a positive tipping point happens when information previously considered 'noise' or irrelevant (Ollinaho, 2016) becomes a meaningful signal (O'Brien and Klein 2017; O'Brien 2020) that can trigger fundamental changes in social norms, behaviours and lifestyles consistent with Earth system boundaries (Rockström et al., 2023). The tipping occurs when a sufficiently large number of people recognise and act upon the information.

Broadly speaking, human information and knowledge systems (HIKS) (Tàbara and Chabay, 2013) comprise both the agents and the mediating mechanisms that generate, store, select and interpret information and turn it into actionable knowledge. Examples of HIKS include economic instruments such as market prices that indicate the current value of things, from commodities to countries; written, oral and computer languages, technologies and libraries; education and research institutions; and other information providers, including social media, that frame and render information salient. HIKS may be understood as **foundational systems influencing how humans interact with each other and the natural world.** As such, they are a core part of the enabling or constraining conditions that can accelerate or restrain cultural and structural transformations towards sustainability.

The capacity to reinterpret information previously dismissed as irrelevant 'noise' into meaningful information worthy of action requires higher-order individual and social learning abilities. New knowledge and beliefs replace those that are no longer fit for purpose. At the societal level, the consequences of a tipping point in HIKS can reorient all forms of human endeavour, from scientific research to technology innovation to governance (Ollinago, 2016).

The regenerative sustainability paradigm (Tàbara 2023; Fazey et al., 2020) describes how positive tipping points could emerge in multiple HIKS. This paradigm calls for the dissolution of the dominant worldview that disregards existential ESTP risks, in favour of a new restorative one that prioritises a thriving human future (Tàbara 2023; Fazey et al., 2020). Such a paradigm would establish new HIKs to help guide sectors towards sustainable pathways, for example HIKS on regenerative food and agriculture.

4.4.2 Political systems

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Summary

In this subchapter we discuss the role of the political domain, both as an enabler of positive tipping within social systems and as a system that can itself be tipped. Political systems can enable change through new policies, investments and discourses. These measures can amplify positive feedbacks and enable new system trajectories, solidifying transformations and making them difficult to reverse. Political systems can also be tipped, either via internal, self-reinforcing dynamics or as a result of acute events (e.g. crises that change the priorities of the electorate). Tipping dynamics within the political system include abrupt changes in politics (e.g. change of leaders), policies (e.g. new laws and regulations), or polity (e.g. introduction of new political institutions). Social movements, civil society and strong interest groups can entrench the status quo or be an instigator of change in political systems.

Key messages

- Political systems often reinforce existing social orders, but political action is crucial for significant and sustained progress towards sustainability.
- Political interventions – such as policy and public investments – can support early change, create positive feedback loops and enable positive tipping in key subsystems.
- Political systems, despite being resistant to change, can also be tipped.
- Civil society and social movements can build broad coalitions and mobilise the public, facilitating new policies and the tipping of incumbent political systems.

Recommendations

- Pursue policies to facilitate positive social tipping through increasing returns, compensating losses, and building the autonomy and capacity of agents for change.
- Build international climate clubs to facilitate climate leadership and unlock deeper and broader global climate cooperation that can be amplified by international organisations.

4.4.2.1 Introduction

Political systems involve complex networks of actors embedded within various institutional settings and operating across multiple scales, from hyper-local to global. This complex arrangement of governing institutions has been described as a **climate change regime complex**, as opposed to a comprehensive and integrated regime, and is characterised by loosely interdependent elements that are sometimes conflicting and sometimes reinforcing (Keohane and Victor, 2010). The political regime determines the set of rules and power structure regulating the operation of a government or institutions. Political actors shape and are constrained by the rules and regulations in their particular spheres (e.g. municipal, state, national), and by pressure from their constituents, advocacy coalitions and other interest groups. The political sphere can enable tipping in other subsystems, for example through the introduction of new policies or investments, and can itself tip, resulting in new policy goals, political leaders or regimes. At the same time, political systems can also be conservative forces, sometimes by design, often resisting change and reinforcing existing social orders, power structures and dominant practices.

Political systems as tipping elements have received relatively limited attention in the literature on social tipping and detailed knowledge of the specific mechanisms, feedbacks and temporal and spatial scales are limited. Given the complexity of the political sphere, especially when it comes to the governance of climate change and ESTPs, it may be impossible to detect the exact *point* of tipping and more fruitful to examine tipping *dynamics*, including enabling conditions and feedbacks, and locating the most 'sensitive points' at which to intervene (Mealy et al., 2023; Farmer et al., 2019; Geels and Ayoub, 2023). For example, the policy feedback literature suggests that new technology firms (e.g. offshore wind or electric vehicles) can use their growing lobbying power to shape public policies. Strategic policies and investments can in turn support and reinforce the development of these new technologies and strengthen markets, especially at early stages of a transition, when there are greater costs or risks (Geels and Ayoub, 2023). New technologies and associated markets can create new coalitions that in turn change policy goals and alliances, as well as public discourse. Similarly, public attention can create pressure on policymakers to introduce, remove or strengthen policies or investments. These dynamics are discussed in more detail below.

4.4.2.2 Political systems can enable (or dampen) social tipping

The political system is a key cross-cutting force in driving or preventing rapid social change. Political systems and institutional settings can be drivers of rapid, nonlinear change in other subsystems (e.g. transition to renewable energy) by setting the rules and regulations that govern society but also by providing capital to different sectors, building out the capacity of relevant agencies, incentivising investment of private capital, investing in public goods such as research and development into new, risky or underprovided technologies, subsidising 'desirable' goods or taxing 'undesirable' ones, or through the discourse they promote and public education and communication efforts, which can in turn create new social norms. The state can thus play an 'entrepreneurial' role by facilitating technological breakthroughs and transformative innovation (Mazzucato, 2011, 2015).

Innovation-focused public interventions can act as enablers of social tipping by fostering technological progress and workforce development, potentially altering public sentiment and increasing political will for sustainable policies, while ensuring a just transition and addressing opposition to change through compensation for those adversely affected. The impacts of such public interventions can be both direct and indirect. For example, the Inflation Reduction Act in the US, which includes $369bn in funding to tackle climate change, much of it directed at renewable energy investments, is also driving indirect change and positive feedbacks by catalysing private-sector investments, the development of new, cheaper green technologies, and policymaking in other countries. This echoes related work, which shows that the adoption of carbon pricing in one country can explain its subsequent adoption in others (Linsenmeier et al., 2023).

Indeed, networked or polycentric forms of governance may support rapid social change by creating interdependence across locations and the potential for positive feedbacks as new innovations and policies take hold (Chapin, 2021). For example, cities involved in programmes such as ICLEI and C40 Cities have come together around the goal of sustainability, deliberately creating global city networks to foster rapid social change through policy experimentation, capacity building and the diffusion of information and innovations." (Bhowmik et al., 2020).

Political systems can of course also dampen feedbacks, limit climate action and reinforce the status quo – as is evident in sizeable fossil fuel subsidies and tax credits, limited renewable energy infrastructure, and lack of a meaningful carbon tax across countries. This may happen in part because of the checks and balances built into democratic systems, but also because those in power serve limited terms and so focus on shorter-term outcomes in their policymaking, have an incentive to respond to present constituents rather than future generations or populations in other locations, often have vested interests in current systems, including fossil fuel-based energy systems, and face intense lobbying from the oil and gas industry, among others (Köhler et al., 2019; Besley and Persson, 2022). Further, politicians may perceive constituents to have limited desire for climate policy (Kneuer, 2012; Stokes, 2016; Willis, 2018) due to widespread misperceptions of public sentiment and large silent majorities and vocal dissenting minorities (Mildenberger and Tingley, 2019). Different institutional forms or regimes determine the distribution of power between government, businesses and publics, and incentivise different coalition-building strategies and policy-shaping efforts (Meckling and Karplus, 2023).

Political systems can thus enable or impede rapid social change and positive social tipping in other subsystems. Ultimately, **climate politics are distributive politics**, resulting in political battles over who reaps the benefits and who bears the costs of climate policy (Meckling and Karplus, 2023). Strategic policy design should thus include both measures to **enable desired change** in key subsystems, such as the renewable energy sector, and to **mitigate impeding factors**, including backlash from key constituents, as enumerated below.

1. Identify policies with concentrated benefits but diffuse costs. Rooftop solar panel subsidies, for example, have concentrated benefits for homeowners and solar panel manufacturers and installers, while the costs are spread across taxpayers.
2. Link climate policy with popular and salient issues. The expansion of renewable energy production through wind and solar, for example, reduces the dependence on fossil fuels and Green House Gases (GHG) emissions but also increases energy independence and security.
3. Combine policies that impose visible/concentrated costs with compensation mechanisms that create visible/concentrated benefits. Carbon fee and dividend schemes, for example, require companies to pay a fee based on their emissions, which is returned to the public in the form of dividends or rebates, compensating for higher prices. Another example is strategic workforce training and placement for those left structurally unemployed due to a transition away from fossil fuels.
4. Ensure policy durability by building positive feedbacks and path dependencies into the policy design. Sequence when benefits or costs are introduced, such as subsidising costs until new technologies take hold, and providing benefits to key political groups.
5. Ensure state capacity and autonomy to enforce policies. To accelerate the build-out of clean energy infrastructure, the capacity of permitting agencies to efficiently and effectively assess projects could be increased through larger staff, better training and more power to advance processes (Bozuwa and Mulvaney, 2023).

4.4.2.3 Political systems themselves can tip

The political sphere may itself constitute a tipping element. In political systems, tipping can occur at the level of policy, politics or polity and involves a complex arrangement of actors (Eder and Stadelmann-Steffen, 2023). For example, extreme events such as natural disasters or long-lasting crises such as the COVID-19 pandemic can change the political landscape by altering public perceptions and behaviour (Casoria et al., 2021), pressure on incumbents (Oliver and Reeves, 2015), and the process by which new measures are introduced (e.g. under disaster declarations), potentially opening windows of opportunity for the introduction of new policies, investments and discourse. Political regimes and policies can tip, as happened with the dissolution of the Soviet Union in 1991 (Kramer, 2022), as can political majorities and, ultimately, leadership. Indeed, this is one of the core principles of democracy: leadership can change rapidly as the priorities of constituents evolve (Eder and Stadelmann-Steffen, 2023; Yankelovich, 2006). However, while new governments may seek to quickly reverse policies introduced by prior governments, many actions, such as investments in large infrastructure projects (e.g. as needed for energy system transformation or nuclear phase-out), are characterised by strong path dependencies and lock-in of development pathways (Thacker et al., 2019) and can thus be considered nearly 'irreversible'. This inertia built into certain infrastructures, technologies, institutions and social norms can create carbon lock-in, but also has the potential to lock in low-emissions pathways (Urge-Vorsatz et al., 2018).

An example of tipping in policy that was driven by tipping in politics is Germany's rapid phase-out of nuclear energy following the Fukushima Daiichi nuclear disaster (Eder and Stadelmann-Steffen, 2023). While this example is largely negative when assessed in terms of emissions and climate goals, it is nonetheless an illustrative example of tipping in politics. In Germany, rapid changes in sentiment among the public and the governing majority (the CDU-FDP coalition in Germany) led to the rapid phase-out of nuclear energy, including the shutting down of several operating power plants. In Switzerland, in contrast, while a political majority also showed signs of tipping towards nuclear phase-out, the decision was gradual. These differences have been attributed to Germany's 'critical state' prior to Fukushima, due to the public's scepticism towards nuclear energy since the Chernobyl meltdown in 1986, and a well-established anti-nuclear movement. They also point to differences in the institutional context. In Germany, the CDU-FDP government coalition held a parliamentary majority and abruptly changed its position. Conversely, in Switzerland compromises and coalitions had to be formed in parliament to phase out nuclear energy.

4.4.2.4 Civil society and political tipping: The role of social movements and coalition formation

To date, most countries have taken relatively modest action on climate change. This has been the case for a host of reasons, including those mentioned in section 4.2.3.3 on dampening effects. One reason for the lack of political will to fight climate change stems from policymakers' beliefs (including in non-democratic regimes) that they lack the mandate for drastic climate policies (Kneuer 2012; Stokes, 2015; Willis 2018). Indeed, research has shown that there are substantial misperceptions among political actors regarding the policy preferences of their constituents, including underestimation of support for a carbon tax (Mildenberger and Tingley, 2019). Civic and political behaviour, including voting behaviour, diverse forms of political participation and the emergence of effective social movements, increases the visibility of public preferences, puts pressure on incumbents to take action on climate change, and can even lead to new leadership (Kuran, 1989). For instance, the German Energiewende/EEG law, which was crucial for initiating the global solar power boom (see Chapter 4.2), would not have been possible without social change in German society, which brought the Green Party into government in 1998 (Hake et al., 2015). Similarly, the CFC ban to protect the ozone layer was also facilitated by shifts in social norms, mass boycotts of products containing CFCs, and public demand for laws banning chlorofluorocarbons (CFC) (Stadelmann-Steffen et al., 2021).

Civil society plays a crucial role in creating enabling conditions for political tipping. Successful social movements, such as the transnational abolitionist movement, played a huge role in shifting societal perceptions and norms and ultimately effecting political change by advocating for the moral unacceptability of slavery. They did so through publications, public education, public responses to arguments, appealing to opponents' values, placing actors of change in core institutions, mass petitioning, litigation, supporting slavery victims and boycotting slave-produced goods, and through leading by example (e.g. former slave owners freeing slaves) (Oldfield, 2013). Crucially, the movement understood the need to create links with policymakers and the importance of building political coalitions. They also made use of litigation, using progressive national law to advance their cause. A similar strategy is increasingly adopted by climate movements. For example, in the Youth plaintiffs in Held vs. State of Montana (US) Climate Case, a judge ruled in August 2023 that it is against the constitution for a state to fail to consider climate change when approving new fossil fuel projects. The national law referenced in this case was the right of state residents (in this case the young plaintiffs) to a clean and healthy environment, including a stable climate. The interplay of national law and civil society enforcing accountability could be a powerful driver for political and social change.

Key challenges for social movements in the longer term include maintaining the authenticity of the message, the commitment and the mutual trust of the base of support, while also leveraging the connections and resources of the wider political network and coalition (Newell, 2015). In democratic countries, coalitions for radical policy change are unlikely to succeed until politicians are first emboldened by the political legitimacy of a broad, popular mandate (DNZ, 2021; Newell, Daley, and Twena, 2021; Willis, 2020). Advocacy for radical change therefore begins in social movements and proceeds, over years and decades, to build coalitions to persuade 'the changeable people…' (Commissioner Tim Kasser, quoted in Newell et al., 2021, p.43).

Although a simple, linear sequence may be of limited use in describing the interdependent complexities of rapid social change, it could be argued that it typically begins with the problem/issue, proceeding with a political process, and ultimately becoming a policy process (Smith, 2022), as summarised in Figure 4.4.4.

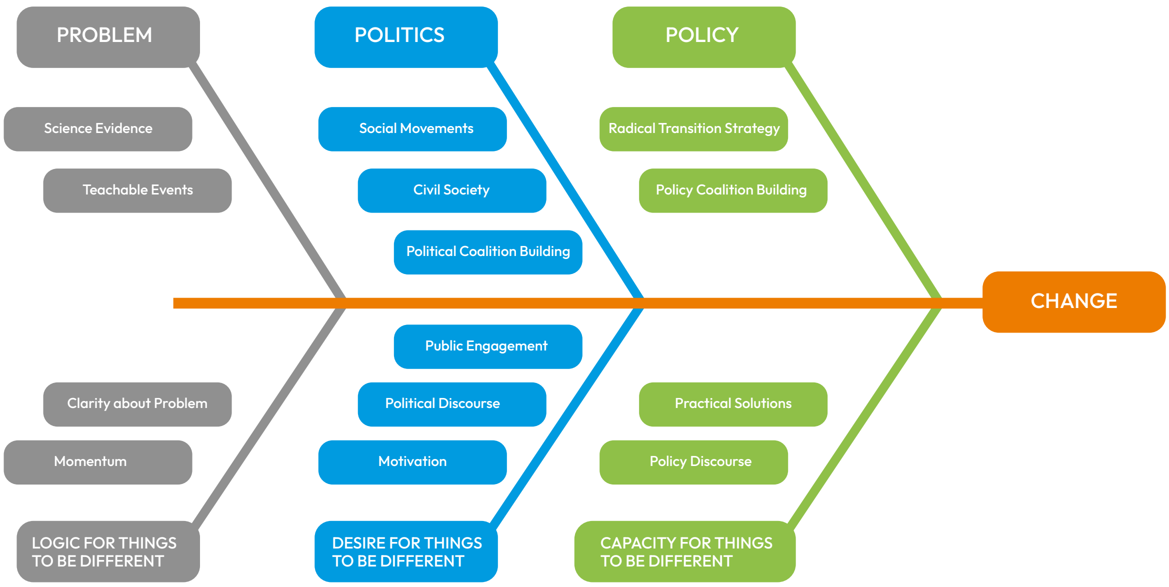

Figure 4.4.4: Sequence of rapid social change.

4.4.2.5 International climate governance and the diffusion of political change

Achieving global climate targets requires some degree of international cooperation, but a key question is how many cooperators are needed at the outset to sustain and increase decarbonisation goals over time. For many years, international climate negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) were predicated on a consensus model, which resulted in weak agreements (e.g. the Kyoto Protocol). Even the Paris Agreement can be regarded as weak, as it outlines a strong set of collective goals (e.g. limit the rise of global temperatures to well below 2°C) but leaves countries largely free to choose the actions needed to meet them (Sharpe, 2023) with limited mechanisms to hold them accountable to their pledges.

Recent work emphasises that **broad consensus may not be the only or most promising pathway** to addressing climate change. To date, global cooperation has been insufficient and difficult to enforce, and none of the world's largest emitters are on target to meet the goals of the Paris Agreement (Carbon Tracker). Many have argued that the lack of cooperation may stem from concerns about free-riding or from the view that addressing climate-change is a zero-sum game (Barrett 2003), made worse by the presence of catastrophic tipping points with uncertain thresholds (Barrett and Dannenberg, 2014). However, addressing climate change is in the interest of certain countries, regardless of whether all countries cooperate (Mildenberger and Aklin, 2020). For example, certain countries may have strong domestic constituencies committed to climate action (e.g. a concerned public or special interest groups and lobbying groups), which may drive their leaders to take mitigative action regardless of whether other countries act. Other countries may face greater exposure to unmitigated climate change and may thus choose to act, or to come together to pressure other countries to take action, as has happened with the Small Island Developing States (SIDS) and the establishment of the Loss and Damage Fund at COP27.

Pioneering states and small-group coalitions may be able to catalyse virtuous cycles of cooperation on climate change due to three features of mitigation efforts that challenge the zero-sum game view (Hale, 2020):

1. **Shared benefits**: Investments in public goods, such as mitigation of GHG emissions, can also confer private benefits.
2. **Diverse preferences**: Different countries attach varying levels of importance to mitigation, which means that some countries will take action despite inaction by others.
3. **Increasing returns**: Previous mitigation efforts enhance the benefits and decrease the costs of future actions through a positive feedback mechanism.

One way to increase ambition is thus through the creation of climate clubs – i.e. a small group of countries committed to ambitious climate goals and deeper cooperation that might involve sectoral agreements and corporate partners. Climate clubs can act as 'tipping sets' which, by switching to a more desirable equilibrium state, can lead others to follow (Grimalda et al., 2022; Heal and Kunreuther, 2011). A few key countries, especially large emitters, working together to speed up the development of green technologies coupled with well-designed broad-based market mechanisms could help accelerate global progress on climate change (Sharpe, 2023). Additionally, such climate clubs can concentrate negotiation power (Meckling and Karplus, 2023) and can be crucial for establishing new norms such as anti-fossil fuel norms (Green, 2018; van Asselt and Green, 2022; Meckling and Karplus, 2023; Linsenmeier et al., 2023). International institutions can in turn amplify this cycle through information sharing, capacity building and the elevation of certain norms (Park, 2006; Meckling and Karplus, 2023).

International norms have been described as evolving according to a patterned 'life cycle' (Finnemore and Sikkink, 1998). Norm entrepreneurs convince states to adopt norms that they deem desirable or appropriate – e.g. the conceptualisation of climate change as an issue of justice and fairness (Mitchell and Carpenter, 2019). If a critical mass adopts the new norm, this can, under certain conditions, create a tipping point after which it spreads, eventually becoming institutionalised. For example, in recent years, SIDS have acted as agenda- and norm-setters in international climate negotiations (Corbett et al., 2019; Constantino et al., 2023). A global coalition of 132 co-sponsoring countries and a global campaign with more than 1,500 civil society organisations in 130 countries formed around Vanuatu's call in 2019 for climate justice. This movement led to the 2023 adoption by consensus of a historic resolution to seek an advisory opinion from the International Court of Justice (ICJ) on the obligations of governments to protect human rights threatened by climate change under international law during the 77th session of the United Nations General Assembly (Vanuatu ICJ Initiative, 2023).

International law can also serve as a trigger for positive social tipping. One example is the introduction of formalised human rights laws, which spread to over 100 countries in three decades (Kim, 2013). In the context of Earth system tipping, a transnational network is advocating for the inclusion of ecocide, defined by an Independent Expert Panel (2021) as "unlawful or wanton acts committed with knowledge that there is a substantial likelihood of severe and either widespread or long-term damage to the environment being caused by those acts", as the 'fifth core crime' in the ICC (International Criminal Court) Statute. As Robinson (2022) argues, including ecocide as the fifth core international crime, or even an international ecocide convention, would "provide stronger penal sanctions, stigmatisation, jurisdictional reach, and commitments to prosecute in relation to the worst environmental crimes. But perhaps an even greater value of the crime is its 'expressive function': reframing massive environmental wrongdoing not as a mere regulatory infraction, but rather as one of the gravest crimes warranting international concern". Such an international law would be a strong signal, shifting expectations and hence social and global norms. It is notable that the International Corporate Governance Network (ICGN), a global investor-led network, called for criminalising ecocide during COP26 (2021) to channel international finances away from ecologically destructive practices.

In summary, political systems can **enable** or **impede** positive social tipping in other key subsystems, and can also **be tipped**. However, political systems are complex, ranging across local to global scales and varying in type of regime, and contingent. Additional research is needed to understand how they tip under different conditions. In this chapter, rather than focusing on identifying exact tipping points, we have focused on highlighting political enabling factors that may help initiate or amplify change in other subsystems, and addressed impeding factors, introducing some key historical and present examples in energy systems transitions. We have also identified mechanisms by which different components of political systems may themselves tip, and the role of social movements in bringing these changes about. This review is by no means comprehensive, and we expect many insights to come from ongoing and novel research efforts into this crucial component of rapid societal change.

4.4.3 Financial systems

Authors: Nadia Ameli, Hugues Chenet, Max Falkenberg, Sumit Kothari, Jamie Rickman, Francesco Lamperti

Summary

As of today, the financial sector is fuelling an economy currently on a trajectory towards ~3°C by 2100. Leveraging the tipping elements inherent in financial markets will be critical to direct the economies onto a net-zero emission trajectory compatible with the 1.5°C-2°C goal of the Paris Agreement. Taken together, the mechanisms we describe in this section highlight the positive tipping points that can be triggered within the financial system and emphasise the necessity of policy interventions to activate and capitalise on these dynamics. The financial system must assume a central role in expediting the shift towards a net-zero carbon economy. For this, the alignment of expectations between investors and policymakers is key, requiring clear transition plans and strategies. Utilisation of public finance, reduction of capital costs and attainment of low-carbon investment thresholds in the Global South and Global North are also indispensable to ensure capital allocation towards where it is most needed. Coordination will be essential to foster implementation of robust financial regulations along with industrial and climate policy. 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.

Key messages

- The financial system must assume a central role in accelerating the shift towards a net-zero carbon economy.
- Policy interventions can activate nonlinear changes to enable transformative shifts within and beyond the financial sector, capitalising on these dynamics.

Recommendations

- The role of the financial system in the transition to a net-zero economy must be clearly articulated and aligned to an industrial strategy. The rules and regulations governing the system can be adjusted accordingly.
- Public finance and policy support should be used to mitigate market uncertainty and encourage private investment, particularly to developing economies. Policy mixes that combine state-based and market-based instruments can initiate virtuous circles that drive innovation and reduce the overall need for public investment.
- Prudent regulatory and financial supervision tools should be used to facilitate a managed decline in fossil fuel lending. Coordinated planning through institutions like the Net Zero Banking Alliance could help manage the transition in debt and equity markets.

4.4.3.1 Introduction

The transition to a net-zero carbon economy relies on financial markets adopting sustainable practices to unlock low-carbon opportunities, accelerate emissions reduction and nature conservation efforts, and mitigate societal and financial risks associated with carbon-stranded assets. The financial system must both finance the 'green' (the desirable) and stop financing the 'dirty' (the undesirable), while managing financial risk-adjusted returns as its primary function (fiduciary duty). However financial markets tend to replicate by default the economy as it is, as they do not a priori 'have a plan' for the economy, whether high or low carbon. The existing economic framework largely operates within an accumulation paradigm driven by search for short-term profits, inadequate climate policy and unclear industrial priorities at both national and international levels. In this context, perpetuating historical patterns is still the best way to ensure profitability. Driven by backward-looking, climate-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 are still allocating capital to fossil fuel assets, consolidating and even creating new carbon lock-ins (FTM, 2023), thereby constructing their own exposure to future climate-related financial risk. However, it is now clear that those investments are not 'needed' from an energy-demand perspective (IEA, 2023a).

To be effective at accelerating the transition, financial markets need to be forced to move beyond their conventional emphasis on financial risk and return, short-term horizons, prevailing market rules and operations, and would need to integrate systemic sustainability considerations into regulation and market practices across the entire financial chain (including investors, financers, financial services, rating agencies and more). Progress thus far does not match the needed pace and depth of transformation. It has been essentially limited to reframing (such as addressing climate-related financial risk), repackaging (as seen in the case of green bonds) and disclosure (with the establishment of the Task Force on Climate-Related Disclosures (TCFD) and similar initiatives), and has not yet led to a significant reallocation of financial capital at global scale. However, **the potential exists for swift and nonlinear changes that can drive transformative shifts within and beyond the financial sector**. In this way, the financial system can be an enabler of positive tipping points in other sectoral systems, in the 'real economy', and may itself exhibit tipping point behaviours.

On the positive side, the financial sector's engagement with climate change has nevertheless undergone a significant evolution over the last decade. Key milestones, such as the 2015 Paris Agreement and Mark Carney's (former Bank of England Governor) influential speech on climate-related financial risks, have catalysed a new discourse connecting finance and climate change and prompting financial actors to embark on a different path (Farmer et al., 2019). The formation of voluntary initiatives like the private-led Glasgow Financial Alliance for Net Zero (GFANZ) and the central bank-led Network of Central Banks and Supervisors for Greening the Financial System (NGFS), exemplifies the growing commitment of financial entities, from private institutions to public authorities, to align themselves with climate targets beyond their traditional perimeter. While not yet having led to transformative actions, these coalitions in their respective domains aim to achieve net-zero carbon emissions by 2050, which questions the role of finance in addressing the challenges posed by climate change – either by challenging the historical role and responsibilities of financial institutions vis-à-vis invested and financed companies, or through renewed approaches to financial supervision, credit and monetary policy (Chenet 2023; Lamperti et al., 2021).

These shifts have the potential to surpass crucial thresholds or tipping points, where a small change can trigger a larger, irreversible transformation, with feedback effects acting as amplifiers. By influencing the allocation of capital to different sectors or activities, the financial system has the power to affect the evolution and composition of the real economy. Often, the financial system has functioned to amplify oscillations, whether positive or negative, through reinforcing feedback mechanisms such as the financial accelerator, contagion, bank runs and assets' fire sales (Bernanke et al., 1999; Delli Gatti et al., 2010). However, finance doesn't just magnify economic shocks – it may also assume a crucial role in enabling technological revolutions (Perez, 2003). Financial actors – and public investors most prominently (Mazzucato, 2013) – actively contribute to the advancement and implementation of innovative technologies, 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', while other mechanisms can also operate concurrently. For instance, once a particular path is established, it can lead to a self-reinforcing cycle where the initial choice gains momentum and becomes increasingly difficult to change (Arthur, 1989). **Finance, thus has the capacity to expedite or impede the dissemination of new products and technologies**, particularly those of utmost importance for the transition to a low-carbon future.

4.4.3.2 Feedbacks between public and private finance

Public finance plays a pivotal role in stimulating new investment by encouraging private investors to follow suit (Mazzucato, 2013). This is not only due to the substantial amount of funding provided by public actors, such as public investment banks and governmental agencies, but also to the quality of financing schemes they offer. Public financing, with its long-term time horizons, favourable repayment conditions, and support services, resembles the role of financial entrepreneurs (Perez, 2003).

By minimising risks associated with investments and supporting specific technological trajectories, public finance can mitigate market uncertainty, potentially enabling tipping points in the financing of low-carbon projects and assets (Campiglio and Lamperti, 2021; Mazzucato and Semieniuk, 2018). However, adequate policy support, such as mission-oriented industrial policies, is essential to facilitate these tipping dynamics.

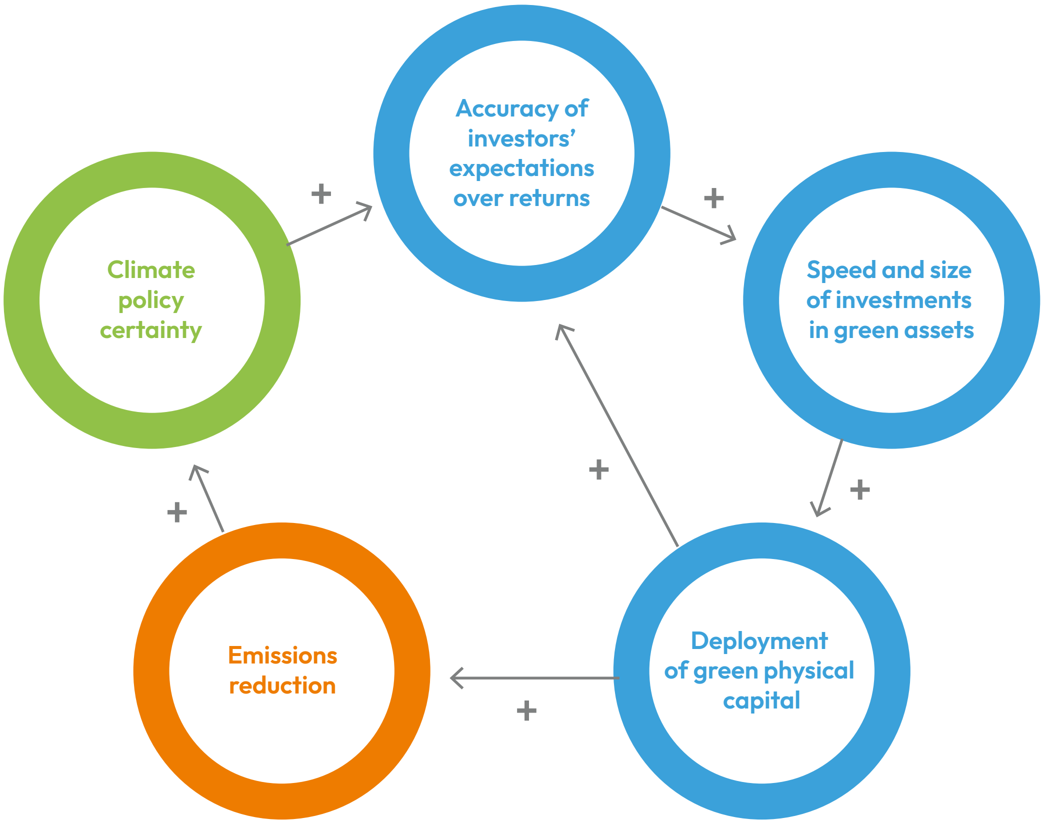

Figure 4.4.5: The figure shows the set of self-reinforcing mechanisms and feedback loops occurring in the process between climate policy certainty and deployment of green physical capital. Expectation alignment creates a positive feedback which can be triggered and sustained by certainty in climate policy. The + symbol indicates a positive effect.

Expectation alignment on the timing and speed of the transition is an additional tipping element that can scale up sustainable investment (Campiglio and Lamperti, 2021; Campiglio et al., 2023; see Figure 4.4.6). Uncertainty about the future prospects of low-carbon assets and unclear information about the strength of climate policy can lead to conservative wait-and-see approaches among investors, especially private ones. However, certainty regarding future climate policy schedules can signal the long-term trajectory of the economy, establishing a positive correlation between macroeconomic performance and the returns of low-carbon assets. For example, the public Contracts for Difference scheme in the UK provided policy certainty on low-carbon electricity generation and triggered large private investments, expanding the stock of offshore wind capacity and lowering power generation costs well below conventional sources. Further, the alignment of beliefs can coordinate and shift the strategies of long-term institutional investors, transforming low-carbon investment from diversification assets to strategic ones and increasing the risk of carbon-intensive assets. Clear and trustworthy climate policy is key for such an alignment to occur. This shift would reduce the cost of capital for low-carbon firms, facilitate their growth, and create a virtuous feedback loop of low-carbon investment.

4.4.3.3 Strategic policy intervention

Two finance-related interventions identified by Farmer et al., (2019) include financial disclosure and the early identification of combinations of new technologies to invest in. Such actions can be interpreted as small **kicks** that can initiate behavioural changes or endogenous shifts in the system's dynamics. Changes in accounting standards and disclosure requirements can significantly alter the value of fossil assets, limiting the development of new projects, reducing committed emissions and thus facilitating the transformation of the energy industry (Le Ravalec et al., 2022; Rambaud and Chenet, 2021). Additionally, low-carbon technologies, given their capital-intensive nature, are subject to much higher investment risk than fossil fuel-based incumbents (Schmidt, 2014). Such risk needs to be managed and/or diversified. Hence, focusing resources on specific technological complementarities (e.g. solar PV and energy storage) as early as possible, rather than investing across a broad range of options, can accelerate the development and deployment of novel and unproven technologies. This **concentration of resources and identification of complementarities reduces uncertainty** surrounding new technologies and enhances the spread of related knowledge and experience.

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 (Robalino and Lempert, 2000). 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 element.

4.4.3.4 Accelerating renewables investment in the Global South

While issues related to finance are central for the Global South in the face of climate change, these countries are essentially ignored by 'sustainable finance' due to the limited role of financial markets in their economies. **In developing economies, policy support can help to overcome climate investment traps due to high costs of accessing finance** (Ameli et al., 2021).

Financial constraints, including underdeveloped capital markets and limited capital stock, prevent these countries from obtaining sufficient funds for low-carbon investments. This creates a self-reinforcing cycle 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, causing adverse impacts on production systems, economic output, unemployment, and political stability (figure 4.4.6).

To address this challenge, a reinforcing feedback cycle has the potential to function in the opposite (desirable) direction with the right changes in action. For instance, appropriate policies that reduce capital costs can act as tipping elements in facilitating the low-carbon transition. Measures like credit guarantee schemes can shift risk away from private investors, resulting in lower capital costs. This would enable developing economies to achieve higher levels of low-carbon electricity deployment and faster emissions reduction in the order of a decade earlier than without such reductions (Ameli et al., 2021).

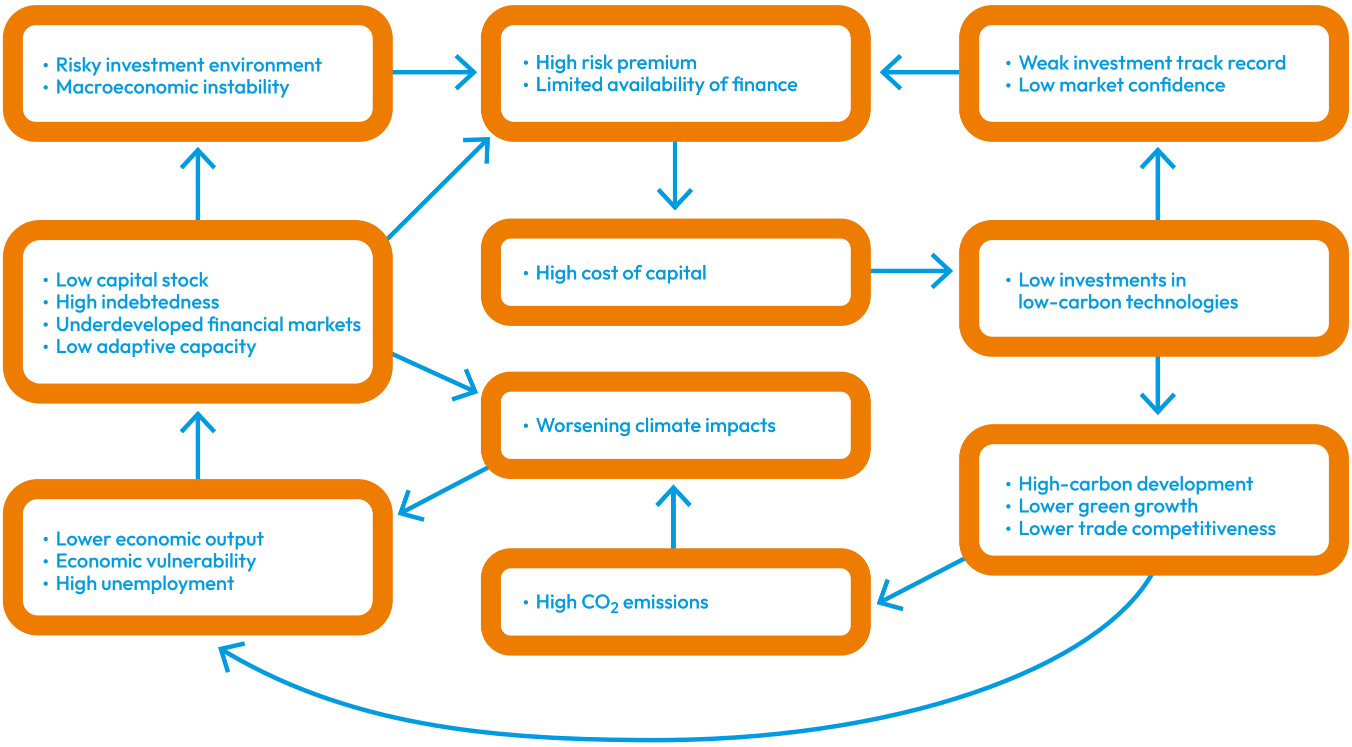

Figure 4.4.6: The figure shows the set of self-reinforcing mechanisms and feedback loops occurring in developing economies characterised by the high cost of capital and limited track records in renewable investments. The strength of these links is strongly linked to local conditions implying that the set of self-reinforcing mechanisms could be exacerbated (or less relevant) in some economies.

Additionally, the flow of international capital into renewable projects in developing countries is influenced by path-dependency, creating a tipping element in the scaling up of renewable investments (Rickman et al., 2023a). Countries with a track record of renewable investments are more likely to attract future investments, leading to positive feedback loops within renewable energy markets (Figure 4.4.6). As countries build a track record in renewables, market confidence grows, bringing down financing costs and attracting further investments in a virtuous cycle. Indeed, there is a nonlinear relationship between the probability of private investment and a country's track record in renewables (Rickman et al., 2023a).

Once a significant capacity base of around 1GW (of wind or solar) is installed, a tipping point is reached and the attractiveness of a market for new investment increases sharply (Figure 4.4.7). However, this also results in an 'investment lock-in, where historical inequalities in financing across countries and income groups persist over time. To escape this investment lock-in, **developing countries must mobilise sustained investment to build a renewables track record that can attract private finance at scale**. Low-income developing countries often fall below this threshold, highlighting the need for sustained investment in holistic energy roadmaps to unlock private finance. Innovative financial and policy mechanisms that target the evolution of a renewables sector can initiate path-dependent flows from private sources and leverage tipping elements in the renewable finance ecosystem.

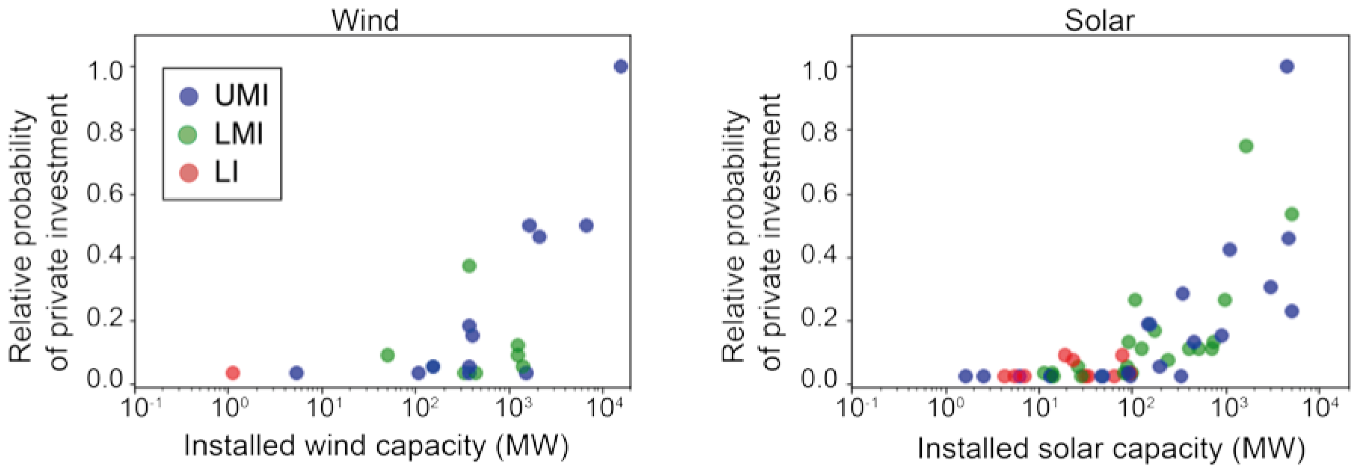

Figure 4.4.7: Empirical relationship between relative probability of private investment and installed wind and solar capacity (Rickman et al., 2023a). Plots show the relative probability of private investment for each country in the post-Paris Agreement period against installed capacity as of 2019, using IEA statistics. Probabilities are normalised against the country with the highest probability of private investment (wind: Brazil, solar: Mexico). Upper middle income (UMI), lower middle income (LMI) and low income (LI).

4.4.3.5 Tipping points in financing of fossil fuels

Over the last decade, the notions of **carbon bubble** and **stranded assets** have been at the core of the attention of financial institutions involved in the fossil fuel sector. Additionally, theoretical modelling reveals tipping elements in the global network of banks which supply debt to the fossil fuel industry (Rickman et al., 2023b). While fossil fuel debt markets are resilient to the unregulated phase-out of capital, the introduction of capital requirements rules (e.g. setting limits on banks' fossil fuel investments based on their capital reserves) can trigger a rapid contraction of fossil fuel debt flows.

The tipping point depends on the stringency of rules and can be reached sooner if large banks lead the phase-out. Appropriate capital requirements rules, developed by standard-setting bodies and regulators, can facilitate a managed and smooth decline in fossil fuel lending. Banks should also coordinate transition plans through alliances like the Net Zero Banking Alliance to enhance their collective impact on debt markets.

4.4.4 Digitalisation

Authors: Elena Verdolini, Charlie Wilson, Felix Creutzig, Luis Martinez, Raphaela Maier, Viktoria Spaiser

Summary

Digital technologies have the potential to support decarbonisation and promote positive tipping points (PTPs)in all sectors and countries. Digitalisation has many possible applications that can accelerate socio-economic transformations towards a post-carbon, regenerative society. Taking three examples from earlier sector analyses – teleworking, Mobility-as-a-Service (MaaS) and smart homes – we show that establishing supportive systemic structures and action to limit rebound effects are needed to harness the positive impact potential of digital technologies. These systemic structures rely on targeted regulations and public policy to establish enabling conditions and avoid the risk of unsustainable impacts. Digital technologies can act as **multipliers of change** because they can unlock and promote broader economic and social benefits alongside efficiency gains.

Key messages

- Digital technologies are already helping enable positive tipping points for renewable electricity and light road transport – they push energy efficiency, enable an electricity system anchored on renewable electricity and allow much higher asset utilisation – and they are likely to be part of prospective positive tipping points in other sectors.
- Given their pervasive and disruptive nature, digital technologies have the potential to be **leverage points**, promoting positive tipping in all sectors, as well as **super-leverage points**, capable of catalysing tipping cascades across multiple sectors and promoting the creation of inclusive economies and societies characterised by high wellbeing.
- Policies are needed to **govern** the digital revolution, with the aim of harnessing the potential enabling role of digital technologies with respect to positive tipping points and cascades towards climate mitigation, and more broadly to sustainable development.

Recommendations

- Use a public policy framework that prohibits or limits environmental degradation while promoting the purposeful use of digital technologies as an enabler of positive tipping points and positive tipping cascades.
- Implement rules and regulations to ensure that the benefits of digitalisation do not accrue to specific parts of societies, or to specific countries, but are diffused and used to harness their mitigation potential in key sectors across user groups.
- The public sector needs to invest in capacity building, including the development of skills for the purposeful use of digital technology and the granting of access to the appropriate digital hardware, software and infrastructure,
- A culture of sustainability and purposeful action needs to be established.

4.4.4.1 Introduction

The digital revolution describes the major restructuring of all domains of social life and of the economy as firms and consumers take advantage of new digital technologies – i.e. ubiquitous connected consumer devices such as mobile phones (Grubler et al.,2018), global internet infrastructure and access (World Bank, 2014), computing devices, sensors and digital communication technologies (Verma et al., 2020). Digital technologies have extraordinary enabling powers: they provide access to information, contribute to forming preferences, modify demand choices, and change the way in which goods and services are provided and accessed (IEA 2017, Nakicenovic et al., 2018).

This subchapter discusses the enabling role that digital technologies and devices can play in the context of PTPs (Lenton et al., 2022). Addressing this topic is important given the lively debate on whether the digital revolution will contribute to the achievement of a low-carbon, sustainable future or whether the rapid diffusion of digital technologies will simply exacerbate existing economic and social inequalities both within and across countries (Nakicenovic et al., 2018; Nature, 2020). Indeed, the 'twin green and digital transformation' is increasingly referred to as a challenge of unprecedented breadth and depth, scale and speed (European Commission 2020; IPCC, 2022; Shukla et al., 2022; Verdolini, 2023).

Digitalisation has myriad possible applications that can be utilised to accelerate socio-economic transformations towards a post-carbon, regenerative society and we cannot cover all possible benefits. We focus on three specific examples: teleworking, MaaS and smart homes, given their relevance for the case studies presented in 4.3.1 and 4.3.2.3.

4.4.4.2 Conceptual underpinnings

Digital technologies have the potential to play two distinct positive roles in the context of the climate and sustainability transitions: they can act as enablers and multipliers of change. **Digital technologies** are **enablers of change** because they underpin the development of the next generation of large-scale, distributed, coordinated, renewable and smart systems by providing sophisticated techniques for controlling, monitoring, managing, optimising and balancing electricity supply and demand (see for instance IEA, 2017; Kangas et al., 2021; Giotitsas et al., 2022). They also contribute to energy efficiency, support energy demand management, promote platform-based sharing economies, and, in a more general sense, enable virtualisation and servitisation, with associated reductions in material inputs (Grubler et al.,2018; Royal Society, 2020; GESI, 2022).

In addition, digital technologies act as **multipliers of change** because they can unlock and promote broader economic and social benefits alongside-energy efficiency gains (Xu et al., 2022). These are often referred to as co-benefits of the energy transition. For instance, digital technologies increase the ability to access products and services, they increase competitiveness and go hand in hand with the up-skilling of the labour force, and the improvement of the quality of jobs. Xu et al. (2022), for instance, find human capital accumulation (measured in terms of educational attainment) as one of the mechanisms by which digitalisation helps reduce energy demand. Digital technologies also enable transformative agency through increased and improved coordination and the creation of digital spaces for action and interaction.

Given their pervasive and disruptive nature, digital technologies ave the potential to be used as strategic interventions or leverage points to enable positive tipping in all sectors as well as super-leverage points capable of catalysing tipping cascades across multiple sectors and promote the creation of inclusive economies and societies characterised by high wellbeing.

In this context, ensuring democratic access to knowledge systems and digital technologies, distributing rents from these knowledge systems fairly, and establishing a governance framework within which digital technologies can contribute to the public good, are strategic interventions to ensure that digitalisation can play its roles of enabler and multiplier of change and that its potential as a leverage point promoting **domain-specific PTPs** can unfold (Box 4.4.2).

Box 4.4.2: Potential risks of digital technologies for sustainable change

While digitalisation can enable positive sustainable change, an increasingly rich literature illustrates how digital technologies can also create significant risks for it (Creutzig et al., 2022; Verdolini, 2023). First, they themselves are energy-intensive and may contribute to increasing energy demand (Freitag et al., 2022). Indeed, the evidence on the energy efficiency (and low demand) potential resulting from digitalisation presents mixed results. Some studies, e.g. Li et al., 2023, show an inverse linear relationship as a function of income (GDP): lower-income countries benefit more in terms of improved energy intensity or reduced energy demand because digitalisation helps avoid or leapfrog existing inefficiencies.

Conversely, other studies (e.g. Xu et al., 2022) show a U-shaped relationship describing how lower and higher-income countries benefit more in terms of efficiency gains, while middle-income countries benefit less. In the latter, scale effects appear to outweigh efficiency gains. Second, they require an increasingly diverse set of material resources (such as rare earth elements) which are sometimes/often sourced from developing countries through unfair labour practices and which later turn into large piles of digital waste. Third, they can be used to increase social and behavioural control and to promote new consumption practices which put further strain on the Earth's resources. Fourth, their wider societal co-benefits do not necessarily accrue equally across countries, regions and sectors: they often are concentrated within the wealthiest individuals in the wealthiest economies.

The costs associated with digital technologies in terms of materials and digital waste weigh more on poorer countries (Creutzig et al., 2022). Digitalisation, and in particular AI, is accelerating the spread of misinformation and leads to further concentration of (economic) power by monopolising information and knowledge systems (Galaz et al., 2023). Misinformation and the concentration of power create conditions in which mistrust of dominant actors spreads to governance institutions more broadly. This set of factors, in turn, may erode support for stringent climate policies whose effective implementation depends on social consensus, too, hinders action for sustainability (2.3).

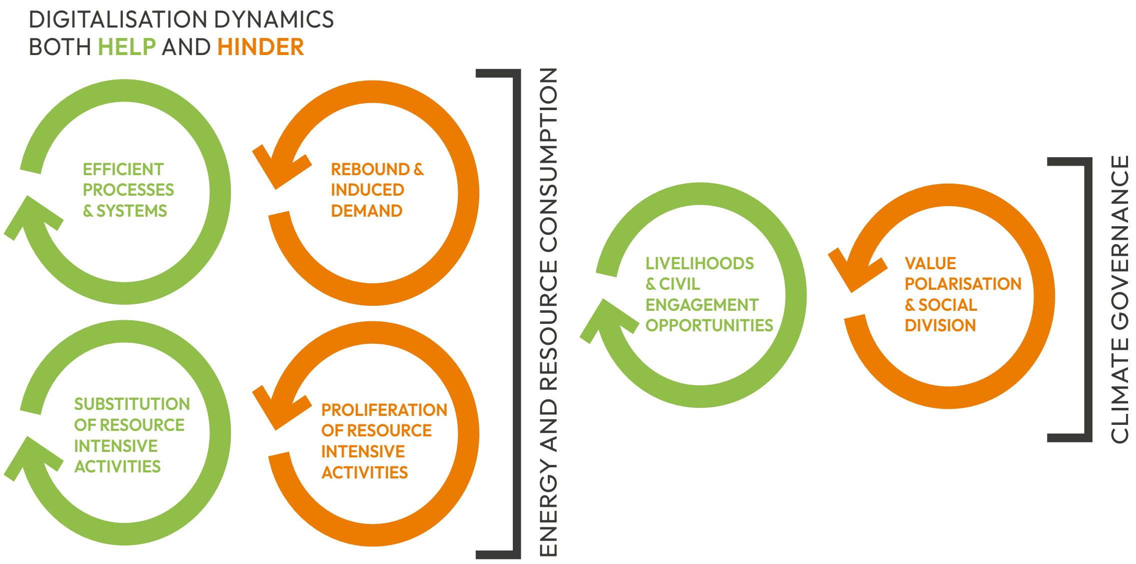

Figure 4.4.8: Illustrative representation of digitalisation impacts on resource use (left panel) and on governance institutions (right panel).

We present here illustrative examples of the transformative potential of digital technologies as enablers of PTPs on the basis of the **avoid, shift, improve framework** (Creutzig et al., 2022) in relation to teleworking, MaaS and smart homes.

4.4.4.3 Digital technologies and avoid options: Teleworking

Recent analysis, spurred by the forced use of telework during the COVID-19 pandemic, explores the potential emission reductions linked with remote working thanks to the availability of ICT and digital technologies such as computers, cloud services, and remote access to networks. Teleworking not only changes how people commute to work but also how and where they travel for their other everyday business (Bohman et al., 2021; Elldér, 2020). For workers, teleworking represents a chance for higher flexibility and autonomy and improved work/life balance; for employers, it often leads to reduced costs and increased employee productivity (European Parliament, 2021). At societal level, it is worth exploring how telework can be designed as an intervention within a policy package to successfully transform currently unsustainable transportation systems into sustainable ones that **avoid** GHG emissions and other impacts.

There is increasing evidence that teleworking affects both carbon emissions and spatial development (European Parliament, 2021). For the specific case of Austria, Heinfellner et al., (2020) argue that about 40 per cent of the workforce could potentially resort to telework, leading to about 1.4 per cent reduction in Austria's GHG emissions from passenger transport, net of rebound effects. Analysing data on the desirability of telework from a survey and through a focus group in a case study for Austria, Maier et al., (2022) conclude that telework might function as a potential positive tipping intervention to move passenger transport on to a low-carbon trajectory. The surveyed respondents showed high willingness to engage in telework and accept various incentives that support low-carbon mobility (personal agency).

However, only with attractive framework conditions (societal agency) will this personal willingness lead to tangible emission reductions. Key reinforcing feedbacks of teleworking as part of a broader tipping point to a lower-mobility paradigm go beyond the direct positive environmental impacts due to a decrease in traffic congestion and carbon emissions, and include (1) improving the mental wellbeing of workers by sparing them the stress of long journeys to and from work, (2) commuting time and travel costs savings and (3) long-lasting impact on the spatial distribution of work and economic activities away from city centres, to the benefit of peripheral geographical locations (e.g. suburbs) (European Parliament, 2021). This, in turn, would make working and living in peripheral areas more attractive and reduce pressure and environmental impacts associated with commuting and life in cities.

Yet, realising the full transformative potential of teleworking is conditional on the availability of digital work equipment (e.g. laptop, monitor, printer) and appropriate home office space, as well as access to a fast and stable internet connection and the ability to securely access documentation through either intranet or cloud services. For people to not only switch to teleworking but also transition to sustainable transportation modes, there is a need to establish supportive systemic structures. Telework should not be viewed as an isolated measure; it can unlock its full potential as a transformative intervention when integrated into a comprehensive policy package that includes incentives for low-carbon mobility.

Beneficial outcomes of telework for energy demand and GHG emissions are not a given. A systematic review of 39 pre-pandemic telework studies found evidence of increases in both non-work travel and home energy use (Hook et al., 2020). The telework PTP therefore requires ancillary action to limit rebound effects (more motorised travel, additional leisure travel) for example through higher fuel taxes and better parking management (Ceccato et al., 2022). In the longer term, teleworking may have an uncertain systemic effect on housing preferences, real estate markets, and (de)urbanisation should teleworkers seek to move out of cities and into larger homes.

Workers lacking access to appropriate digital devices, services and skills, as well as suitable domestic conditions, will have lower willingness or capacity to engage in telework practices, preventing the achievement of a PTP. Tackling the digital divide in its various forms therefore represents a sensitive intervention point to fully capitalise on the enabling potential of digital technologies supporting teleworking.

4.4.4.4 Digital technologies and shift options: Mobility-as-a-Service

Digital technologies underpin the diffusion of MaaS, namely the supply of a range of mobility services through a single digital customer interface. MaaS integrates different transport, information and payment services into a smooth and reliable customer experience. It can include traditional public transport, car, scooter or bike sharing and demand-responsive modes, allowing multi-modal, door-to-door travel using a single platform and potentially replacing the need for vehicle ownership (e.g. car, motorcycle, bicycle or scooter). MaaS therefore allows consumers to **shift** between different mobility options and, importantly, away from carbon-intensive options towards more sustainable modes of transportation, including public transport, active travel, micro-mobility and shared modes (OECD/ITF, 2020; Kamargianni et al., 2016).

MaaS is an emerging framework of transport systems. Several test cases can be found in Helsinki with an application called Whim developed by MaaS Global, which allows planning and using a cab, metro, light rail, bus, car or bicycle and paying with a QR code. In Vienna, the Wien Mobil app integrates public transportation, self-service bicycles, car-sharing, cabs, scooters and parking lots. In Djakarta, a case study demonstrated that shared motorcycle services improve mobility, but not GHG emissions (Suatmadi et al., 2019). Payment for public transport can be done in the application, yet there is no integrated multimodal fare between different operators in the platform. Similarly, Hannover developed an application called Mobility Shop, which provides access to public transport, car-sharing and cabs. The app assists with trip planning, and all mobility is paid with a monthly invoice automatically debited from a user's bank account.

The achievement of PTP's in the context of MaaS is linked to whole-system adoption, particularly in the context of moving towards less carbon-intensive modes, including micro-mobility and ridesharing efficiency. The value and utility of MaaS increases with its penetration rate. On the one hand, as more travellers resort to it, the value of using MaaS will increase for all users. In addition, it would also enhance non-user motivation to explore MaaS.

The high mitigation potential of MaaS in the transportation sector fundamentally depends on the ability of digital applications to reduce frictions and promote coordination. MaaS can reduce transport CO_2 emissions by encouraging modal shifts and changing vehicle ownership patterns.

Nevertheless, the results may only be limited once this model is sufficiently implemented to change lifestyles and social norms. Leveraging the benefits of MaaS options requires limiting rebound effects and problematic inefficient solutions by regulations and public policy (Creutzig et al., 2019). Some evidence of short-term impacts for partially implemented systems were assessed by the project MAASiFiE, showing a reduction of eight and a half per cent in emissions due to less car use and some promoted shift to other modes. Other co-benefits are the efficiency, affordability and accessibility for citizens.

The widespread development of MaaS hinges on the availability and reliability of digital devices and interfaces: providers need to be able to access integrated platforms under suitable rules governing competition, pricing and service provision; users need the ability to access requisite digital technologies and skills. Legislative, commercial, governance and technological changes are likely needed to establish MaaS successfully. Several organisational models for a MaaS market involve varying levels of involvement by public authorities.

Similar to the telework case, it therefore requires a public policy framework that both favours new MaaS options, directs outcomes towards public purpose (e.g. lower congestion and GHG emissions), ensures MaaS supports rather than cannibalises public transport, and also limits private motorised transport. MaaS PTP could be a central enabler of a wider strategy to dislodge the private car as the dominant and preferred mobility option, particularly in urban contexts. Resulting societal benefits could be large, but the transformation is socially and politically difficult.

4.4.4.5 Digital technologies and improve options: Smart homes

In smart homes, information and communication technologies (ICTs) are distributed throughout rooms, devices and systems (lighting, heating, energy management); they relay information to users and feed back users' or automated commands to manage the domestic environment (Wilson et al., 2020). Smart homes and smart devices play an important role in demand-side mitigation options: they are the end-use node of the smart energy system that allows consumers to **improve** the use of energy as well as utilities to respond to real-time flows of information on energy demand fed back by smart metres from millions of homes (Hargreaves and Wilson, 2017; Baydia et al., 2021). Thanks to digital devices and technologies, measures aimed at influencing habits through information provision and feedback on energy consumption can in theory result in substantial household energy savings (Jensen et al., 2016; Malmodin and Coroama, 2016; Nilsson et al., 2018). Notwithstanding this high potential, demonstrated energy savings from the limited number of studies on this topic appears to be relatively small but significant (BIT, 2017, Khanna et al., 2022). In the UK, for instance, data from a large-scale trial of smart metres and in-home displays in the UK demonstrated around three per cent energy reductions on average (AECOM, 2011). Potential savings (or 'shaving') during peak times can be more pronounced (Pratt and Erickson, 2020), particularly if linked in-home displays communicating usage and cost information to end-users enable utilities to charge for electricity at its marginal cost, providing a price signal to shift or curtail demand when supply is expensive or in short supply (Srivastava et al., 2018). Yet, households' appetite or capacity for reducing energy bills in response to information feedback and price incentives appears limited, and interest in information and price signals rapidly wears off and is subject to rebound effects that offset demand reductions (Azarova et al., 2020).

Embedding digital technologies and devices in homes turns them from 'passive' (i.e. non-responsive to network needs) end-user nodes in hub-to-spoke energy networks to 'active' (responsive, flexible and integrated) nodes in distributed energy networks. This switch supports the achievement of PTP's in the energy system, as it integrates significantly more renewable energy and faces increased challenges due to widespread electrification of all sectors and activities. This shift is enabled by digitalisation in the domestic environment, with emerging potential for AI applications to help accelerate positive trends (towards informed energy management without required user interventions, and control over distributed end-use, storage and generation resources throughout the building stock).

4.4.4.6 Other domains where digital technologies can enable positive tipping

The three specific applications discussed so far illustrate how digital technologies can enable PTPs and act as multipliers of societal change in the context of the ASI framework. Importantly, digitalisation has myriad possible applications that can be utilised to accelerate socio-economic transformations towards a post-carbon, regenerative society. Indeed, similar dynamics to those described above could be discussed with respect to other sectors and applications. For instance, digital technologies can contribute to avoiding food waste (4.3.4) and improving sustainable consumer practices in the food sector e.g. through digital provenance systems and blockchain-based certification. They can also avoid unnecessary energy demand (Wilson et al., 2020, also 4.3.2), promote pro-environmental behaviours as well as improved practices at the level of urban planning (Milojevic-Dupont and Creutzig, 2021) and favour asset sharing in freight transport (Box 4.3.4.). In the supply side of the energy sector, digital technologies are necessary for the large-scale deployment of smart grids and the integration of prosumers – that is, actors that both consume and produce energy. Other instances in which digital technologies could enable PTPs include:

- **Augmented democracy**, where digitalisation can facilitate inclusive, democratic and yet expert-informed political decision making from local to global (Satorras et al., 2020; Wellings et al., 2023; Nisbett et al. 2022);
- **Carbon/ecological footprint tracking** for individuals, organisations and companies, potentially linked to bank accounts and potentially augmented with conversational AI (Nerini et al., 2021; Wemyss et al., 2023; Nisbett and Spaiser 2023);
- **Digital twins simulations** for sustainable city planning, traffic monitoring systems, manufacturing, green transition planning, etc. (Xia et al., 2022; Bauer et al., 2021).

More generally, advances in digitalisation and AI can enhance our abilities to automate and optimise processes – e.g. coupling production processes such as green hydrogen production to fluctuating renewable energy production processes (Yang et al., 2022). The new generation of large-scale language models (LLMs, which underpin services like ChatGPT), combined with a human loop training iteration, can produce question-specific knowledge to citizens, starting from a curated compilation of the existing literature on planetary health and climate change (Debnath et al., 2023).

4.4.4.7 Strategic interventions

Digital technologies, devices and applications have the potential to support decarbonisation (Blanco et al., 2022) and promote PTPs in all sectors and countries. Yet, this enabling role does not arise independently. Strategic interventions can ensure that digitalisation becomes an enabler for, rather than a barrier to, sustainable change. Importantly, two types of strategies and policies are relevant in this respect. On the one hand, **framework policies need to ensure the social steering of digitalisation** so that its agenda is aligned with that of climate mitigation and more broadly to sustainable development. Second, **specific policies need to be tailored to respond to heterogenous challenges** across sectors as well as within and across countries. A specific challenge common across many sectors is efficiency-induced scale and rebound effects that increase overall levels of consumption if digitalisation makes accessing goods and services cheaper, easier, quicker or more convenient. Such scale and rebound effects would need to be recognised and appropriately dealt with in comprehensive climate policy packages.

4.4.5 Detecting 'early opportunity indicators' for positive tipping points

Authors: Joshua E. Buxton, Chris A. Boulton

Summary

Statistical signals that could provide early warning of Earth system tipping points may also be detectable for positive tipping points. Identifying such signals in key indicators for target systems could provide early indication of opportunities for (for example) policy intervention to accelerate tipping when the resilience of an incumbent system is weakening. They could also be used to monitor the impact of past or future interventions. Because positive tipping points (PTPs) involve complex interactions across different domains of society, it may be useful to assess multiple indicators spanning these dimensions. A case study in electric vehicles (EVs) demonstrates that 'early opportunity indicators' (EOIs) can be detected in market share of internal combustion engine vehicles (ICEVs) as they approach a tipping
point and lose majority market share to EVs. Similar signals can be observed in public interest in EVs, as expressed through advertisement views online.

Key messages

- 'Early opportunity indicators' in key variables can be detected for some positive tipping points.
- This approach could enhance opportunities for intervention to accelerate positive tipping points, or could be used to assess the impact of previous measures.

Recommendations

- Greater focus should be given to identifying potential early opportunity indicators in a range of sociotechnical and other systems that may be important targets for positive tipping points.
- Where possible, variables for EOIs should be chosen that represent more than one dimension of systemic change, for example by assessing sales data and public sentiment in parallel.

4.4.5.1 Predicting tipping points

In some circumstances, tipping points in climate and ecological systems may be preceded by specific statistical signals, termed **early warning signals** (EWS) (see Chapter 1.6). These provide some indication that a system is losing resilience and a self-propelling transition may be approaching. Chapter 2.5 discusses where these EWS may be applied to negative social-ecological tipping points, and here we expand upon this by considering how they may relate to **positive social tipping points** and illustrate this with a case study of the EV transition.

EWS are often observable as a consequence of **critical slowing down** (CSD), which occurs in a system as it loses resilience before a tipping point. When a resilient system with strong restorative feedbacks experiences some perturbation, it will return quickly to its equilibrium state (i.e. a healthy forest recovering from a drought). However, as the system loses resilience, these restorative feedbacks weaken, and the system takes longer to return to equilibrium following a shock. This changing response can be measured to indicate the system's resilience, by measuring the declining return rate (Wissel, 1984). This change can also be measured over time with an increase in the lag-1 autocorrelation (AR(1)), in addition to an expected increase in variance prior to a tipping point (see Chapters 1.6 and 2.5 for further details of this method and other EWS).

While measuring EWS with empirical data is most common in ecological and climate systems, it is not exclusive to these domains and a number of studies have applied this approach to alternate systems, such as health, economics and online social discourse (Dakos et al., 2023). In health sciences, attempts have been made to identify generic EWS prior to disease re-emergence (Proverbio et al., 2022). Several studies have attempted to detect EWS prior to economic shock events, with varying levels of success (Tan et al., 2014; Diks et al., 2019; Wen et al., 2018; See Chapter 2.5). Social media data has also been employed to detect EWS before transitions in online discourse (Pananos et al., 2017) and could be applied to online radicalisation (see Chapter 2.5). These studies often focus on negative shocks, where the shift occurring is to a less desirable alternate state, but it is also possible that these statistical indicators may be present prior to a rapid transition to a more desirable state.

As discussed in the rest of Section 4, positive tipping points may occur in different elements of social systems and across different nested scales. For example, in socio-technical systems, development of a technology may have positive feedback loops which allow it to scale rapidly, reduce in cost and improve in quality: thus becoming more accessible (Sharpe and Lenton, 2021; Farmer and Lafond, 2016; Lam and Mercure, 2022). Rapid changes in social behaviour or perspective may be required to enable this transition. In these complex systems it is likely that **social and technical change will be interlinked**, with each affecting the other. Consequently, for some systems it may be possible to measure changes in resilience within the social sub-system and in the technical or ecological sub-system. There are also likely to be **exogenous shocks** due to policy decisions or external economic factors which will show up in the system and may enable us to measure some element of its resilience. We sketch out these intersecting feedback loops as they may apply to the EV transition in Figure 4.4.8.

There are therefore two potential ways that we might measure the resilience of social systems; i) the **return rate** from a known perturbation or event or ii) the long-term **changes in the resilience** from a longer-term forcing on the system, which can be measured with AR(1). These approaches could be applied to multiple elements or indicators of these systems, either to detect **decreasing** resilience of an incumbent system, or to detect **increasing** resilience in a new, positive social or technological innovation. Here we refer to these indicators as EOIs.

4.4.5.2 Case study: Detecting early opportunity signals indicators in the electric vehicle transition

The transition to EVs has been widely discussed as approaching a tipping point in some countries, and having passed one in others (Meldrum et al,. 2023, see 4.3.2.2). By analysing sales data of EVs (including battery electric vehicles (BEVs) and hybrid electric vehicles (HEVs)), and internal-combustion engine vehicles (ICEVs), we can attempt to detect this transition by measuring the resilience of markets for both the incumbent and the new technology. The EV transition involves strong feedbacks between technological development that makes EVs more affordable, accessible and attractive, and changes in the social domain, including public interest in and perception of EVs (Figure 4.4.8). To understand this social dimension of the transition, we also consider the frequency with which people view EVs in the UK on AutoTrader, an online marketplace site (Boulton et al., 2023).

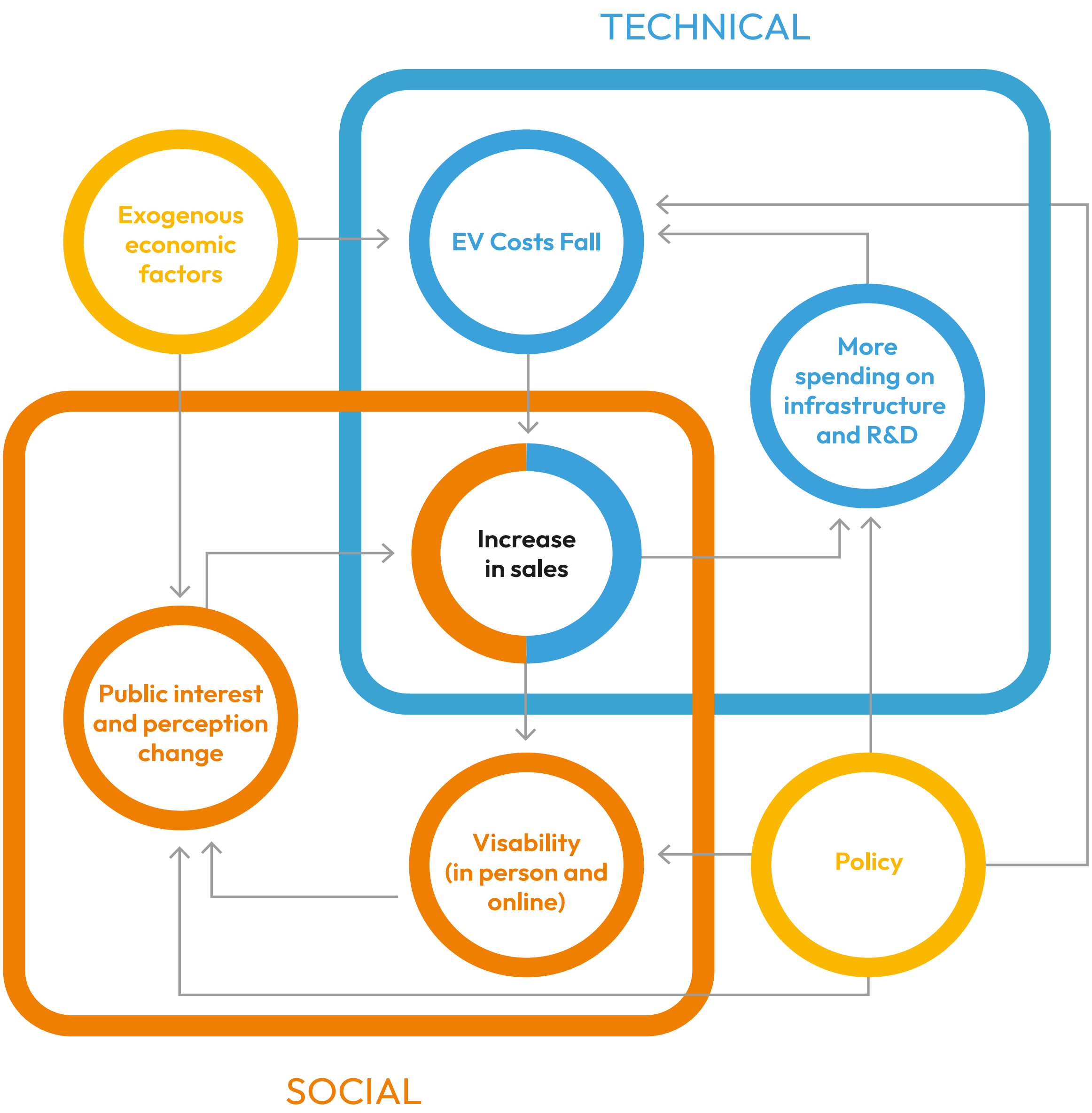

Figure 4.4.9: Simplified causal feedback loop of how the technical and social elements may interact within the EV transition.

Can we measure the resilience of the automotive industry?

If we consider the automotive industry as a complex system, consisting of an interconnected ecosystem of, among other things, production, sales and public preference and needs, then the question arises of whether we can measure the resilience of this system in a comparable way to a 'natural' ecosystem, such as a rainforest.

While numerous factors might affect the stability of this system, such as supply chain resilience, one simple metric is to consider the sales of vehicles. This can be affected by economic shocks, and recovery from shocks could provide an indication of the resilience of this system.

One such event is the 2008 financial crisis which, among other impacts, caused a rapid decline in vehicle sales across many major markets (Figure 4.4.9). For Denmark and the US, this perturbation caused an initial sharp decline in sales, which then recovered over subsequent years. The faster recovery rate of sales in Denmark suggests a more resilient market (and wider economy) than that of the US. Car sales in Greece also suffered because of the wider economic crisis caused by the 2008 financial crisis, and here there is no observable return, with the system tipping into an apparently alternate stable state of very low car sales; thus suggesting very little resilience prior to 2008. The effect of government intervention to support the automotive industry as a significant employer can be seen in Germany, where incentives provided a boost to sales in 2009. A similar scheme in the US resulted in a brief spike in sales that same year, however true recovery took longer, again suggesting lower resilience.

While this approach does not delve deeply into the underlying structure of the automotive industry and the fact that the 2008 financial crisis occurred as a different perturbation in different economies, it illustrates an approach to applying concepts of resilience from the natural sciences to broader socio-economic questions.

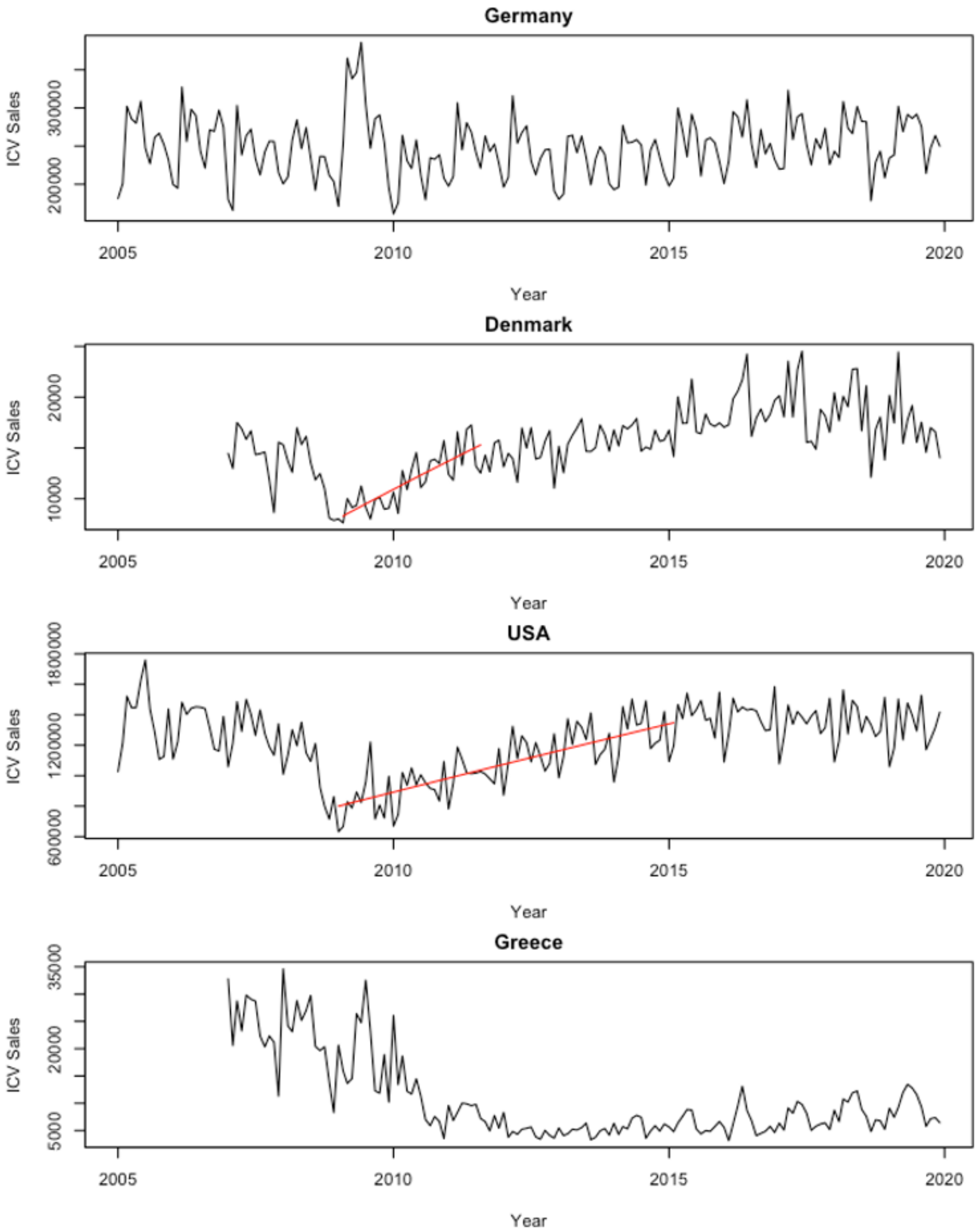

Figure 4.4.10: Sales of automotive vehicles in Germany, Denmark, US and Greece. Red lines in Denmark and USA show recovery from perturbation caused by the 2008 financial crisis. Data unavailable for Denmark and Greece prior to 2007.

4.4.5.3 Resilience change prior to the EV transition tipping point

To understand the changing resilience of the incumbent, ICEV-dominated, system prior to an EV tipping point, we can use the same approach to analyse **market share**, rather than total sales of ICEVs. In the UK, France, Germany and China, the market share underwent a gradual change from January 2009 to December 2019, with ICEVs losing ground, prior to a dramatic and abrupt change in 2020 caused by a surge in sales of EVs and PHEVs (Figure. 4.4.10). Conversely, the US has not yet experienced abrupt change, with ICEVs still accounting for the majority of sales.

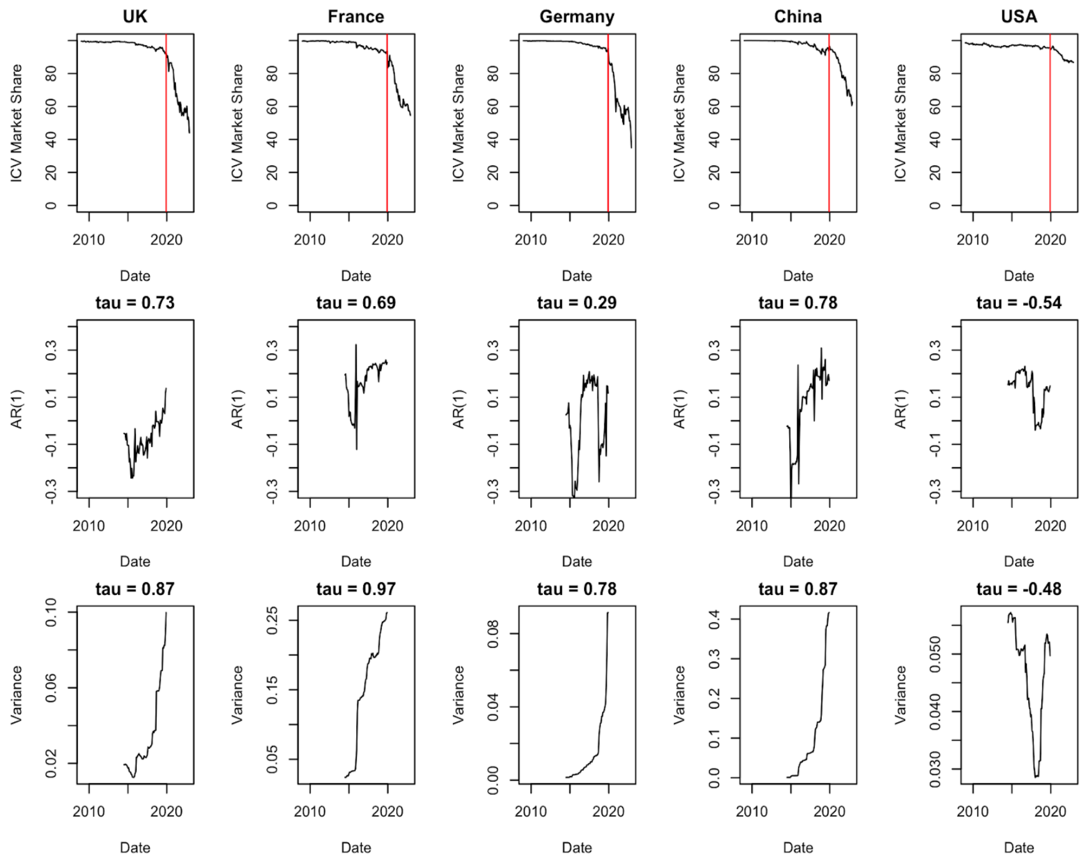

Figure 4.4.11: First row: Changes in ICEV market share in UK, France, Germany, China and US, with December 2019 marked with a red line. Second and third row: Change in AR(1) and variance for each of these countries suggesting a loss of resilience and approaching tipping point prior to the start of 2020. Positive mann-kendall tau trend values above plots imply significant positive trends in these indicators of resilience loss.

AR(1) and variance, as measured across a moving window, increase in three of the four markets that show a tipping point – UK, France and China – however the change in AR(1) is not convincing in Germany. In the US, which does not show this tipping point behaviour, the trend in AR(1) and variance is not positive, as we may expect.

Therefore for some of the markets that are currently experiencing an EV transition, the tipping point was preceded by changes in statistical measures that we observe in natural ecosystem tipping points. This suggests that these changes may be detectable prior to these socio-technical tipping points and could provide a way to monitor when social systems are losing resilience.

4.4.5.4 Changes detectable in other social data?

The attention EVs receive from the general public is a further possible indicator of change (Boulton et al., 2023). A time series of view share (proportion of advert views that are for EV cars rather than non-EV cars) on AutoTrader, a prominent UK website, shows that there has been a general increase in view share from 2018 up to July 2023 (Figure 4.4.11). Also clear is that, at certain times, spikes in attention can occur, a few days after which view share returns to normal.

These spikes in attention can be directly linked to specific external events:

- **I. 4th February, 2020:** The UK Government announces a ban on sale of new petrol vehicles by 2035;
- **II. 18th November, 2020:** The UK Government brings forward the ban on sale of new petrol vehicles to 2030;
- **III. 29th September, 2021:** Potential HGV driver shortage, leading to uncertainty about petrol availability, panic buying and fuel shortages in the UK;
- **IV. 10th March, 2022:** Spike in UK fuel prices associated with international fossil fuel volatility from Russian conflict in Ukraine;
- **V. 8th June, 2022:** Spike in UK fuel prices.

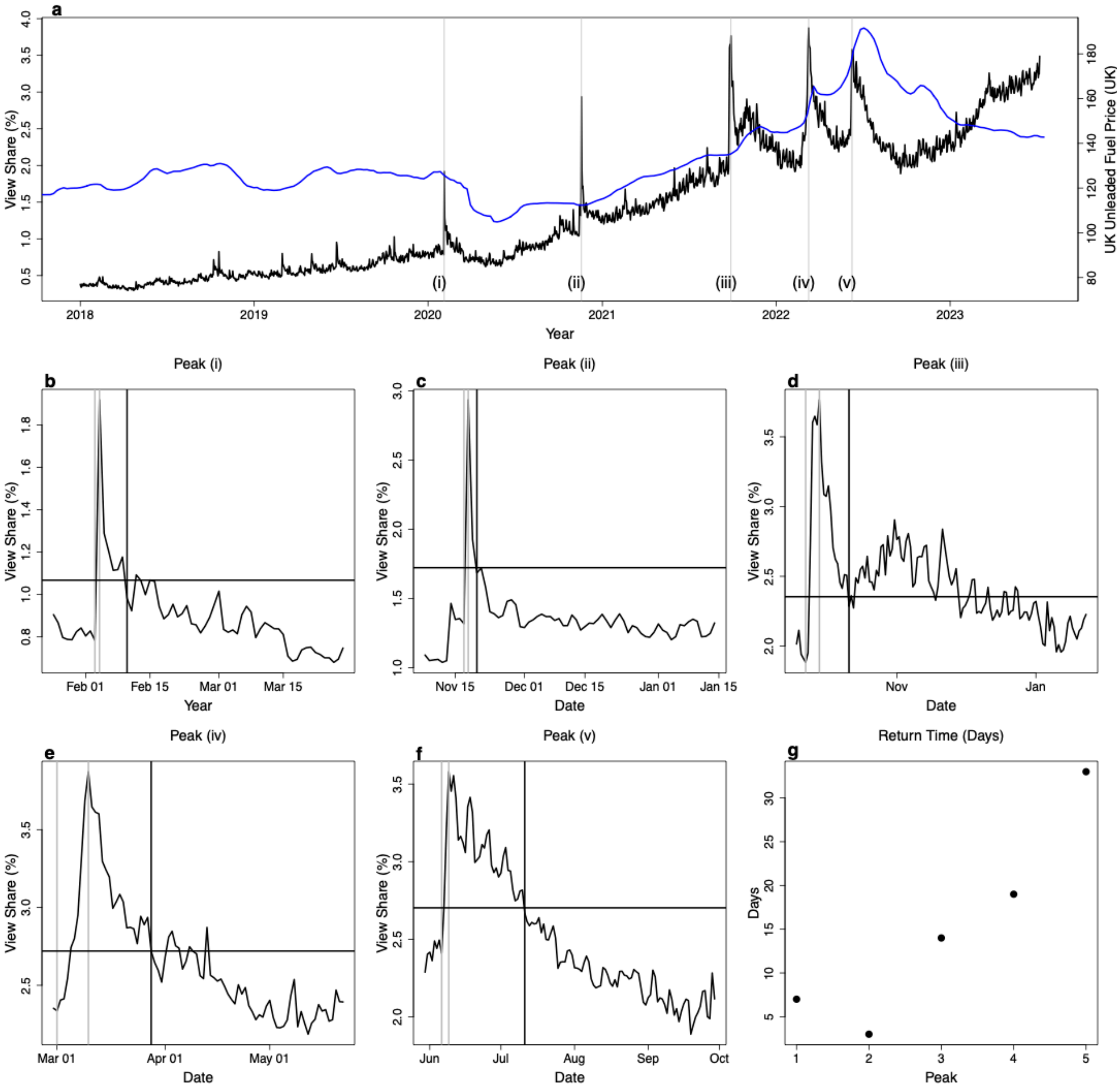

Figure 4.4.12: Measuring the return time from specific events as an EOI in view share of EVs (compared to non-EVs) on AutoTrader UK. (a) The time series of view share (black), alongside the weekly mean UK unleaded fuel price (blue). Marked in grey vertical lines (i-v) are specific external events detailed in the main text. (b)-(f) The return time from each event is calculated as the number of days it takes for the time series to decrease by 75% of the distance from the spike back to the pre-spike value. Dotted grey lines show the pre-spike and spike dates as vertical lines. The 75% value is shown as a horizontal black line, and the date this is reached by the vertical black line. (g) The number of days after the spike it took for the system to reach the 75% value for each spike.

We measure how long it takes for attention to return to 'normal' after each spike (i)-(v) as an early opportunity indicator (see Chapter 1.6 and 2.5), by determining how long it takes for a spike in attention to decay by 75 per cent. For each successive spike (Figure 4.4.11 b-f), there is a clear increase in the length of time it takes for decay to happen, i.e. for the system to return to 75 per cent of its pre-spike level (Figure 4.4.11 g), increasing by a factor of approximately six from point (i) in June 2020, to (v) in June 2022. This shows that the system is slowing down and the incumbent state of ICEV dominance is losing stability over time. Colloquially, one can imagine this increase in return time suggests that events are affecting the system more intensely, such that it takes longer for interest in EVs to die down after the event has passed and that this indicates the system is losing stability. Just as for market share in the sales data, we can also observe increases in AR(1) and variance in view share across the whole period (Figure 4.4.12).

Compared to sales data, this dataset provides the opportunity to measure actors' instantaneous reactions to events, as they do not have to interact with the system in such a strongly committed way such as buying a vehicle. As such, we are able to better determine people's interest using this novel dataset. These results imply that critical slowing down is occuring in the view share of EV adverts, and thus that a tipping point is being approached such that they may rapidly gain the majority of view share.

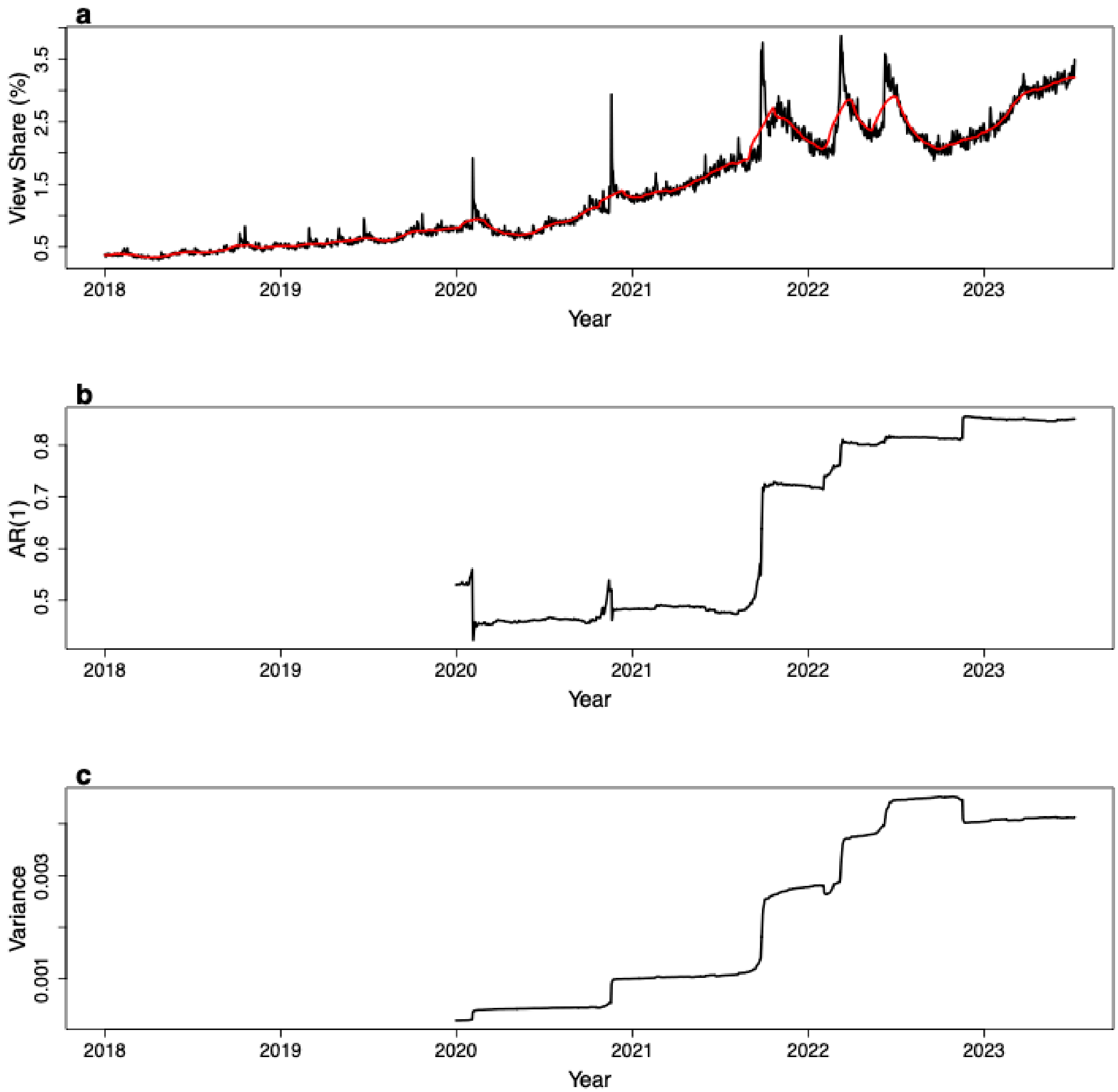

Figure 4.4.13: Early opportunity indicators on EV view share time series. (a) The time series of view share (black) and the smoothed version (red) used to detrend (calculated using a Kernal smoothing function with bandwidth equal to 50). (b) AR(1) calculated from the time series in (a) once it has been detrended using a moving window equal to two years (as described in Chapter 1.6) and plotted at the end of the window used to create it. (c) As in (b) but for variance.

4.4.5.5 Limitations

Attempting to detect EOI in social systems can encounter additional difficulties compared to ecological and climate systems (Chapters 1.6 and 2.5). Careful thought is required when considering other positive tipping points in order to decide which system elements should be monitored and which could show these EOI, as they are likely to be system dependent. The EV transition example is occurring as a substitution; this contains a market shift and some amount of behavioural change (4.3.2), therefore we consider sales and EV adverts. Other positive tipping points will not necessarily have a behavioural aspect, or alternatively may almost exclusively exist as a behavioural and values change. These would require a different framing and would likely be constrained by data availability. These methods require high temporal resolution data which matches the relevant timescale of the system and is sufficient in extent to precede the tipping point. It is uncommon for this data to be available for social systems and careful consideration must be given for which state variable should (and can) be measured in social systems.

Questions also remain about the timescales over which we could detect these changes in resilience and whether they would manifest early enough to offer a substantial lead time compared to other analysis methods, such as expert elicitation.

It is also possible that this resilience loss framing is not consistent across all social systems. One key difference between social and ecological systems is the question of agency; it is possible that people are able to self-correct or that interested actors may try to strengthen the feedbacks which keep a system within an 'undesirable' regime, and that some abrupt transitions may be too rapid (or exogenously caused) to be detectable with EOI. Some social tipping points may have obvious alternate states, such as substitution of an incumbent technology for a new, low-carbon innovation, however this may not always be the case, especially when considering cultural and behavioural changes, and the drivers and likelihoods of these alternate states will differ across countries and cultures.

4.4.5.6 Measuring progress – Early opportunity indicators in other sectors

We have discussed how one might apply EOIs to a socio-technical transition, using the EV transition as a case study. This approach seems to show some success and requires consideration of how we may apply it to other positive tipping points.

We propose that further work is required to investigate these indicators for other PTPs, in order to add value to existing work on determining when tipping points may happen. Some of these system changes may have a social element, such as consumer demand and preferences, and as such social data (where it exists) would be useful here; one such example could involve discourse around plant-based diets and meat alternatives. As well as exogenous drivers, some social tipping points may be strongly driven by network effects and social contagion, such as the agroforestry project TIST discussed in Chapter 4.3 (Box 4.3.9). Network-based statistics can aid in predicting tipping points (Lu et al., 2021; see before Chapter 1.6 for more details) and therefore investigating these networks' structures may explain if and why a tipping point is being approached or where contagion can be facilitated.

These indicators may be observed in datasets which measure different elements of the transition – in this case, ICEV sales and EV advert views. They can give some measure of the effect of external intervention and show how 'resilient' the undesirable status quo is, and therefore how easy or hard it may be to tip out of (in our case study, this is the incumbent ICEV regime). From the EV advert views, we can see that changes in the system response to external perturbations, such as policy announcements and economic factors, offer a way to detect the social response to these. One approach to utilising this is to measure the resilience of the existing (undesirable) regime and to monitor how it responds to interventions, with a system approaching a tipping point showing the largest effect from an intervention. They can therefore be conceived of as both a measure of 'progress' towards a goal, and also as an indicator of when a system is losing resilience and can therefore experience greater return on targeted efforts to push it towards a tipping point.

Chapter 4.5 Positive tipping cascades

Authors: Sibel Eker, Jürgen Scheffran, Timothy M. Lenton, Caroline Zimm, Steven R. Smith, Deepthi Swamy, Tom Powell

Summary

Cascading effects through cross-system interactions is one of the biggest promises of positive tipping points to create rapid climate and sustainability action. Several channels exist through which a strategic input can trigger secondary impacts for a disproportionately large positive response. We need to balance positive and negative feedback loops across systems for managing cascades. There are various agents that can trigger cascades. We need early warning systems and empirical evidence, either based on observational data or simulations, on interventions that can trigger cascades towards and beyond a positive tipping point.

Key messages

- Cascading effects can occur across sociotechnical systems when one sector drives the cost of a shared technology down, or when the output of one sector provides a low cost input to others. Similar relationships exist across sociopolitical systems that amplify the impact of norm, behaviour and policy changes.
- Super-leverage points can exist where interventions can tip multiple systems across multiple sectors in a domino effect. Public authorities and non-governmental agents can both play a role in triggering cascades through super-leverage points.
- Governmental positive tipping interventions for rapid climate and sustainability action can benefit from the indirect influence of policies on society, such as norm-setting. Non-governmental positive tipping interventions can harness the influence of social change on policy, indicated by climate litigation, green voting, discourse change and civic action.
- Cascade management requires all actors from governments to industry and civil society to adopt a systems thinking approach.

Recommendations

- Government, business, finance and research sectors need a coordinated, ideally international, approach to designing and implementing strategies to activate super-leverage points.

  For example, to implement green ammonia blending mandates for fertiliser manufacturing could trigger a tipping point in demand for hydrogen electrolysers, which would reduce the production costs of green hydrogen, and thereby increase the economic viability of green hydrogen-based solutions in other sectors, including steel production and shipping.

4.5.1 Introduction

Positive tipping dynamics have been, or can potentially be, observed in various sociotechnical and environmental systems. Due to (sometimes) strong interconnections between these systems, a positive tipping intervention can lead to a sequence of secondary impacts across different systems (energy, finance, policy, etc) and scales (individual, national, international) and result in a much larger eventual impact. These cross-system interactions also create cascading feedback mechanisms that can further reinforce the positive feedbacks within those systems and accelerate the tipping dynamics, or vice versa. Therefore, identifying and managing such cascades is necessary to accelerate tipping dynamics and boost the effectiveness of positive tipping interventions towards rapid decarbonisation.

The Industrial Revolution in Britain (ca. 1760-1840) provides archetypal examples of cascading effects across the economy. High wages spurred innovation in the substitution of energy for labour; and innovation in cotton manufacturing triggered much wider applications of machines and the new modes of production. Increasing energy demand spurred innovation in resource extraction, in the energy-efficiency of steam engines, and in a transport network to move heavy materials (e.g. coal, iron). That transport network in turn expanded markets for both heavy and pre-existing lighter (organic) goods. Increasing demand for such goods from a growing middle class drove further investment in innovation, increasing productivity and maintaining economic growth.

This chapter describes key examples of cascading effects and feedback loops across various sociotechnical (e.g. energy, transport), social-ecological (e.g. agriculture) and socio-political systems. Besides a better understanding of the state and potential of positive tipping, this chapter sheds light on how such tipping dynamics can be triggered by civil society and the private sector, creating the constituency for government-led interventions, and can be managed by limiting negative cascades and inducing positive ones.

4.5.2 Cross-system interactions leading to cascades

The cross-system interactions within sociotechnical, socioecological and sociopolitical systems can lead to positive tipping cascades. Furthermore, the interactions across society, policy, technology and economy (Figure 4.5.1) can amplify these cascades. Historically, interacting political, technological and behavioural tipping elements such as the Montreal Protocol, development of non-Chlorofluorocarbon (CFCs) substitutes and public concerns over Ultra Violet (UV) radiation and skin cancer, led to a rapid phase-out of ozone-depleting chemicals (Stadelmann-Steffen et al., 2021).

In the near term, cascades across those systems can also lead to rapid decarbonisation. For instance, public procurement of sustainable food can accelerate norm and behaviour changes, enable the use of alternative agricultural practices, such as regenerative agriculture or green ammonia use, by reducing the land pressure, and (with the latter) can facilitate the decarbonisation of energy and transport systems by boosting the production of green hydrogen. Similarly, zero emission vehicle (ZEV) mandates are a strong leverage point due to cascading effects. As policies require manufacturers to ensure ZEVs account for rising proportion of their car sales, they overcome a constraint on supply in the transport sector, facilitate decarbonisation in the energy sector through innovation and raise the demand from the society. Versions of this policy have proved highly effective in California, China and the Canadian provinces of Quebec and British Columbia, combined with installation of charging stations.

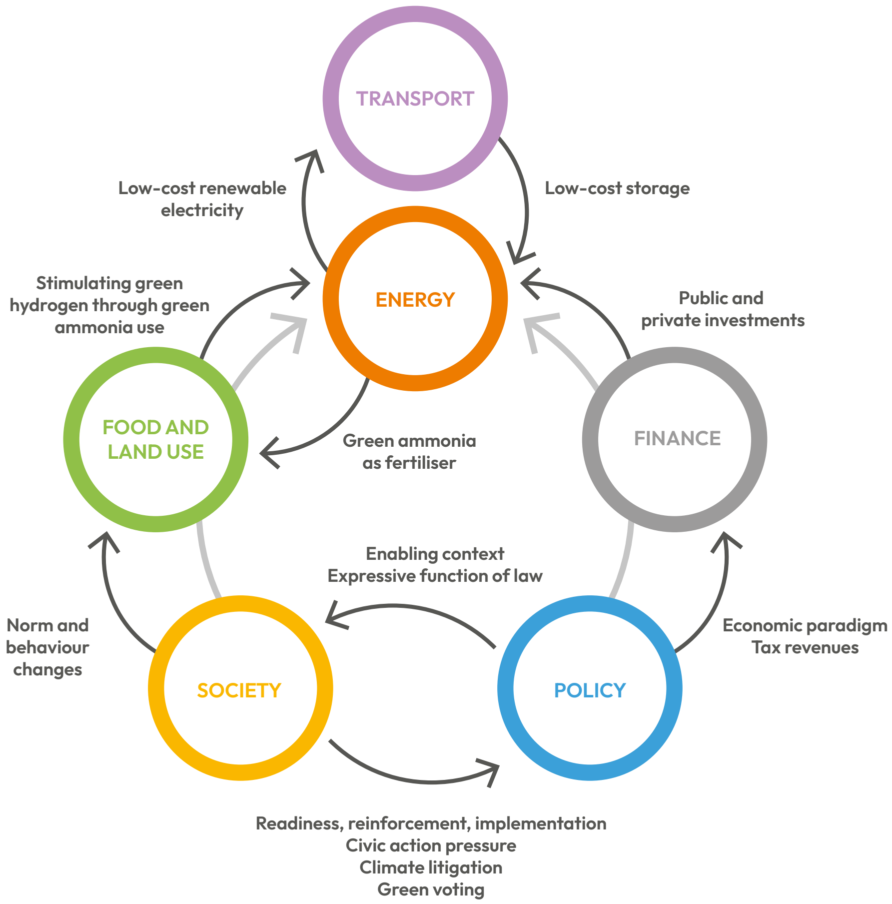

Figure 4.5.1: Overview of the cross-system interactions that can create positive tipping cascades.

Not only public authorities and governments, but many different agents can play a role in triggering the cascades. For instance, thought leaders and media can be pivotal in enhancing the visibility of a population already engaged in climate action, which determines not only the demand for low-carbon goods and services, but also increases the momentum of climate policies and the perceived risk of fossil fuel assets. When such policies and financial developments reduce the fossil fuel supply, the resulting lower costs of low-carbon technologies lead to more people taking climate action by choosing low-carbon options, and creating a reinforcing feedback loop of cross-system cascades (Eker and Wilson, 2022).

Below, we describe these interactions within and between the sociotechnical (energy, transport), socioecological (food and land use) and sociopolitical (society and policy, including finance) systems to highlight the role and ability of various agents in triggering cascades.

4.5.2.1. Cascading effects in sociotechnical systems

Across sociotechnical systems, cascading effects can occur when one sector drives the cost of a shared technology down, or when the output of one sector provides a low-cost input to others. Electricity is a general-purpose technology, and with renewable energy becoming the cheapest source of electricity generation (Way et al., 2022), there is the potential for economy-wide cascading consequences across the electricity sector, mobility and heating (Chapter 4.3). Low-cost renewable power combined with cheaper and longer-duration battery storage is making direct electrification highly attractive in some sectors of the economy (e.g. light-road transport) and more feasible in others (e.g. heavy-duty transport, short-haul shipping and aviation).

Specifically, passenger electric vehicles EVs represent the majority of projected demand for batteries, with estimates suggesting that they will account for ~70 per cent of total installed battery capacity by 2030. At the same time, wider deployment of EVs reduces the battery costs, further reducing the renewables' storage costs in the energy sector. (Meldrum et al, 2023) highlight that boosting EV adoption to 60 per cent of total global passenger vehicle sales by 2030 would increase the total volume of battery production by 10 times from current levels, while a continuation of the currently announced projects would increase the battery production capacity only fourfold from the current levels (IEA, 2023). Given current learning rates, this could drive a 60 per cent reduction in battery costs by 2030. As battery costs account for ~30 per cent of the total cost of renewable power, a 60 per cent reduction in them will bring forward cost parity points of new solar/wind plus storage with new or existing gas (or coal) power generation.

Cheaper batteries provide cost-effective electricity storage also to balance intermittent renewable energy supply and demand, encouraging homeowners to install batteries that charge at low rates during the night and provide power at times of peak demand during the day (4.3.1). Furthermore, declining costs of renewables boosts the use of heat pumps in residential heating, with higher demand for renewables in return (Meldrum et al., 2023). In the mobility sector, cheaper and better-performing batteries, as well as the advancing electric drivetrain technology, are increasing the competitiveness of electric trucks, bringing forward the point where they outcompete petrol or diesel trucks. Linked with advances in digitalisation, this spurs decentralisation of electricity generation (4.4.4 and 4.3.2).

The impact of cheaper electrolysers and renewable energy goes beyond the electricity sector, mobility and home energy, and creates new avenues for industries to decarbonise using green hydrogen and its derivatives. For instance, green ammonia (produced from hydrogen with renewable energy) can be used for agricultural fertilisers, shipping fuel and synthetic jet fuel in aviation. It can also be a storage option to facilitate load balancing in renewable electricity systems (Edmonds et al., 2022, Bouaboula et al., 2023). Green ammonia is already cost competitive in fertiliser production, thanks also to its low transport costs either through pipelines or shipping (IEA, 2019). With economies of scale and learning, progress in green ammonia use for fertilisers could bring down the cost of green hydrogen for use in several other sectors. For example, implementing a 25 per cent green ammonia blending mandate in fertiliser manufacturing could create demand for almost 100 GW of hydrogen electrolysers, which would reduce capital costs by ~70 per cent given current learning rates. This could unlock US$1.5/kg green hydrogen costs if accompanied by continued falls in the cost of clean electricity – helping to close the gap to cost parity or increase the economic viability of zero-emission solutions in other sectors including steel production and shipping.

4.5.2.2 Cascading effects in social-ecological systems

Food and land use is one of the key systems (4.3.3) that can create tipping dynamics for accelerated decarbonisation. Self-reinforcing feedback loops such as increasing returns and technological reinforcement can progressively push an inadequate into a more sustainable food system (Lenton et al., 2022; Fesenfeld L.P et al., 2022).

The role of society is considered a key driver of transformation in the food system, as widespread behaviour changes towards lower waste, sustainable diets and diversified protein sources can not only reduce the GHG emissions of the agriculture sector but also create synergies for achieving multiple SDGs, such as alleviating hunger, improving public health and averting biodiversity loss, and reducing the intensity of the tradeoffs between them (van Vuuren et al., 2018; Leclere et al., 2020; Obersteiner et al., 2016).

As dietary behaviour changes reduce land pressure, fertiliser consumption is expected to decline, and adoption of diversified and regenerative farming practices are expected to increase (Gosnell et al., 2019), as well as ecological restoration and associated carbon sequestration, leading to more rapid decarbonisation in agriculture (4.3.3.5). In climate vulnerable, low-income economies, these feedbacks can also drive diversification of livelihoods, new economic opportunities, and other social benefits (4.3.3.4). Social norms have been repeatedly shown to be a key driver of widespread dietary changes in model-based studies (Eliot, 2022; Eker et al., 2019). Public procurement of sustainable food is considered a strategic intervention to accelerate the adoption of new norms (GSDR, 2023), and food labelling and certification in alternative food networks (Lenton et al., 2022) is key for facilitating market penetration of alternative proteins. Therefore, such triggers in society and policy can have cascading impacts on intensified and accelerated transformation of food and land use systems.

4.5.2.3 Cascading effects in sociopolitical systems

The interaction between society and policy can be key to tipping global carbon emissions by creating cascading effects through individual action, social conformity, public discourse, climate policy and technological learning. For example, simulation results suggest that individual action is ineffectual unless the social credibility of costly behavioural change is high (Moore et al., (2022).

Society affects policy in multiple ways: First, adoption of niche technologies signals readiness for wider policy change; early cost reductions reinforce the policy ambition towards stimulating such technologies further; and coalitions of early adopters influence politics for more aggressive policy response (Schmidt and Sewerin, 2017). Societal readiness affects pro-environmental policies, especially on a local scale, as exemplified by different car-sharing policies of local authorities in the Netherlands (Meelen et al., 2019), different solar photovoltaic policies of German states (Dewald and Truffer, 2012), and the positive tipping dynamics observed in the UK's offshore wind production and EV sales due to policies following an increase in public concern and attention (Geels and Ayoub, 2023). Second, social movements affect policy, either in legislation or in agenda setting. Civic action preceding and during Conference of Parties (COP) (Carattini and Löschel, 2021) and resistance to local fossil fuel projects have been able to cancel or suspend such projects (Piggot, 2018; Temper et al., 2020) or create non-fossil fuel energy policies (Hielscher et al., 2022). In a third and fundamental way, society influences policy through the election of politicians and policymakers. In Europe and the US, for instance, public risk perception has resulted in green voting after extreme climate events (Hazlett and Mildenberger, 2020; Hoffmann et al., 2022), even though income and political identity play a strong mediating role. Therefore, society provides the political legitimacy and democratic mandate that policymakers need to support radical policy change (Willis, 2020; Smith, 2023).

Another socio-political phenomenon that can trigger a tipping cascade is the spike in climate litigation cases worldwide. Climate litigation describes administrative, judicial and other investigatory cases that raise issues of law related to climate change, and it reflects underlying sociocultural changes. Since 2015, climate litigation cases have more than doubled worldwide, surpassing 2,000 in May 2022 (and representing 25 per cent of all cases filed between 2020 and 2022) (Setzer and Higham, 2022). They reflect climate action from diverse citizens (e.g. children in Germany or the Netherlands, grandmothers in Switzerland, a Peruvian farmer against a German energy company) in various jurisdictions (against governments, banks and large corporations in emission-intensive sectors) to advance climate action or to challenge how and which climate policies are implemented.

Policies have a direct and significant impact on society by creating an enabling environment for the adoption of low-carbon technologies and behaviours through financial support, infrastructure design, regulations, standards and bans. For instance, subsidisation of low-carbon energy (Otto et al., 2020) or transport modes, and tax benefits of EVs (Sharpe and Lenton, 2021) are government-led positive tipping interventions that can accelerate the adoption of these technologies and create cascading effects on energy and transport systems (4.3.1 and 4.3.2). Moreover, policies have a secondary impact on society by signalling what is socially approved or disapproved and setting social norms (Hoff and Walsh, 2019), according to a mechanism called the 'expressive function of law' (McAdams, 2015; Sunstein, 1996). Several studies confirm the expressive function of law in other contexts, such as compulsory voting in Switzerland (Funk, 2007), legalising same-sex marriage in the US (Tankard and Paluck, 2017) and social-distancing policies during COVID-19 lockdowns in the UK (Galbiati et al., 2021).

The tipping of socio-political systems can also be triggered by public discourses that have cascading effects on public opinion, political priorities, policymaking, legitimacy, credibility, social norms, values and mobilisation (Dryzek, 1997; Dryzek, 2001; Bradford, 2016). For instance, the Nobel Peace Prize awarded to the Intergovernmental Panel on Climate Change (IPCC) and Al Gore in 2007 marked a tipping point in climate change discourse (Walsh, 2007), contributing to increased global awareness, strengthened political commitment, enhanced credibility for the IPCC, catalysed climate activism, and influenced future global agreements and sub-national actions (Schiermeier and Tollefson, 2007). Similarly, the Earthrise image taken by the Apollo 8 mission crew in 1968 (Poole, 2008) served as a tipping point contributing to a shift in public opinion and environmental awareness (Schroeder, 2009). This and similar images produce what is known as the 'overview effect' (Yaden et al., 2016), evoking a sense of awe and interconnectedness with Earth's systems and inspiring international cooperation in addressing environmental challenges (Logan, Berman, Berman and Prescott, 2020). Some have claimed that the photograph influenced environmental policy and institutions, including the creation of the Environmental Protection Agency (EPA) in the United States (Collins, Genet, and Christian, 2013). Reframing international climate policy from burden-sharing to win-win (Jaeger et al., 2012) is considered a key factor leading to the acceptance of the Paris Agreement, and such transformative win-win narratives in the economic, cultural and financial contexts can also accelerate climate action (Hinkel et al., 2020).

Policies can also create tipping cascades by affecting society through the political-economic system. The societal paradigm shift towards a global neoliberal capitalist economic system in the late 1970s is an intriguing example of a whole-society cascade of change. The crisis of Keynesianism in the late 1970s, the collapse of the Bretton Woods system, the oil price shocks, and trade union disputes, caused a shift in public opinion and provided the political opportunity for Neoliberalism, which used state power to expand the role of markets, competition, and individual responsibility in society. Prior to its ascendency, the Neoliberal project had spent 50 years developing a coherent philosophy, a compelling narrative, a detailed policy portfolio and a network of political support ready for favourable conditions to emerge (Davies and Gane, 2021; Newell, 2018; Brown, 2015; Mirowski and Plehwe, 2015; Burgin, 2012). The historical lessons to be learned in relation to society-wide tipping cascades include the importance of having a portfolio of policies and an effective advocacy coalition ready for a window of political opportunity.

Besides the broader economic system they create, the economic influence of policies on society can lead to positive or negative cascades in more specific ways. For instance, mechanisms like mitigation taxes may create new government revenue streams: a carbon price of $50 per tonne of CO_2 in 2030 is estimated to lead to a rise in government revenue amounting to approximately 1 per cent of GDP for several G20 nations, and significantly higher increases in some countries (IMF/OECD, 2021). On the other hand, as the economy moves away from fossil fuels, tax revenues from carbon-intensive industries and associated sectors such as tourism and agriculture are likely to shrink (Agarwal, et al., 2021; Bachner and Bednar-Friedl, 2018). For example, a climate policy package focused on long-term decarbonisation across the economy in India is estimated to reduce government fuel tax revenues by nearly US$70bn (2018) by 2050 (Swamy, Mitra, Agarwal, Mahajan and Orvis, 2022). The net impact on government revenues from such varied streams can have societal implications on education, infrastructure and healthcare expenditure, which are the means to tip society through awareness and an enabling environment.

4.5.3 Harnessing the power of cascades

Supporting positive cascades is a challenging task, in particular when considering the complex interaction with negative (undesirable) cascades in the human-earth system, which can disrupt positive cascades, but which in turn can help contain negative cascades. Therefore, the key elements of intervention design for positive tipping (4.2.3) to balance reinforcing and dampening feedback mechanisms to avoid unintended consequences are also instrumental in harnessing the power of cross-system cascades.

Integrated human-Earth system models capturing the feedback mechanisms that are identified as potential drivers of tipping dynamics can support understanding of the role of various feedback mechanisms, hence help intervention design for tipping cascades. Scientific literature contains several examples of modelling studies that explore positive tipping dynamics and interventions in specific contexts (Hochrainer-Stigler et al., 2020b; Niamir et al., 2020; Eker et al., 2019), using various methodologies such as system dynamics (top-down feedback perspective), agent-based modelling (behavioural rules) and social network analysis (spread of cascading events). An integrated modelling framework that captures the cascades across sociotechnical, socioecological and sociopolitical systems discussed above (4.5.1) is however still missing. Moreover, the complexity of integrated systems modelling might come at a cost of their interpretability and practical usefulness (Figure 4.5.2). Strong stakeholder engagement might be needed when designing modelling interfaces and scenarios, including dimensions of political economy, power, distribution and justice.

Participatory approaches are valuable not only in utilising models in decision support, but also in harnessing the power of cascades by establishing a shared understanding and systems thinking among multiple actors, as well as supporting cooperative governance.

Cooperative governance coordinates, regulates, manages and controls interdependent social and political relations among multiple actors, including coalitions and organisations of governmental, intergovernmental and non-governmental organisations, all pursuing their own goals and interests. To overcome collective action problems and the tragedy of the commons, various mechanisms offer promising signs of supporting positive tipping cascades: implementing co-benefits and co-evolution; neighbourhood collaboration; transnational initiatives like city networks; coordination of goals, efforts and actions for mitigation and adaptation; bottom-up participation complementary to top-down global negotiations; and regulations and norms. Identifying conflict potentials is important to prevent escalation towards a cycle of conflict and instead induce cycles of cooperation between stakeholders. This depends on the societal responses, involving adaptive agents following their motivations, capabilities and behavioural rules.

Governance of tipping cascades is facing tremendous uncertainties about natural and social impacts and responses (Franzke et al., 2022). Diverse sources of knowledge can help to contain this uncertainty, including scientific data and modelling as well as local and Indigenous knowledge based on experience, mobilised in participatory approaches and collective learning.

Agency benefits from constructive and mutually adaptive behaviour of agents to induce positive tipping cascades across the socio-technical, -ecological, economic, and -political system interactions.

The real difficulty and the major political effort, though, lies in getting to that point in the first place. In order to begin to understand how to get there, and to design and operationalise positive tipping across socio-political sectors, scales and institutions, we can start with understanding the ecologies and dynamics of the key actors and coalitions. We can then use systems thinking across all sectors, scales and research domains to create a shared understanding of how everyone – including local authorities, political parties, artists, NGOs, businesses, financial investors, trade unions, farmers, faith groups, academics, journalists, lawyers and social movement organisers – can contribute to rapid climate action by leveraging their role in positive tipping.

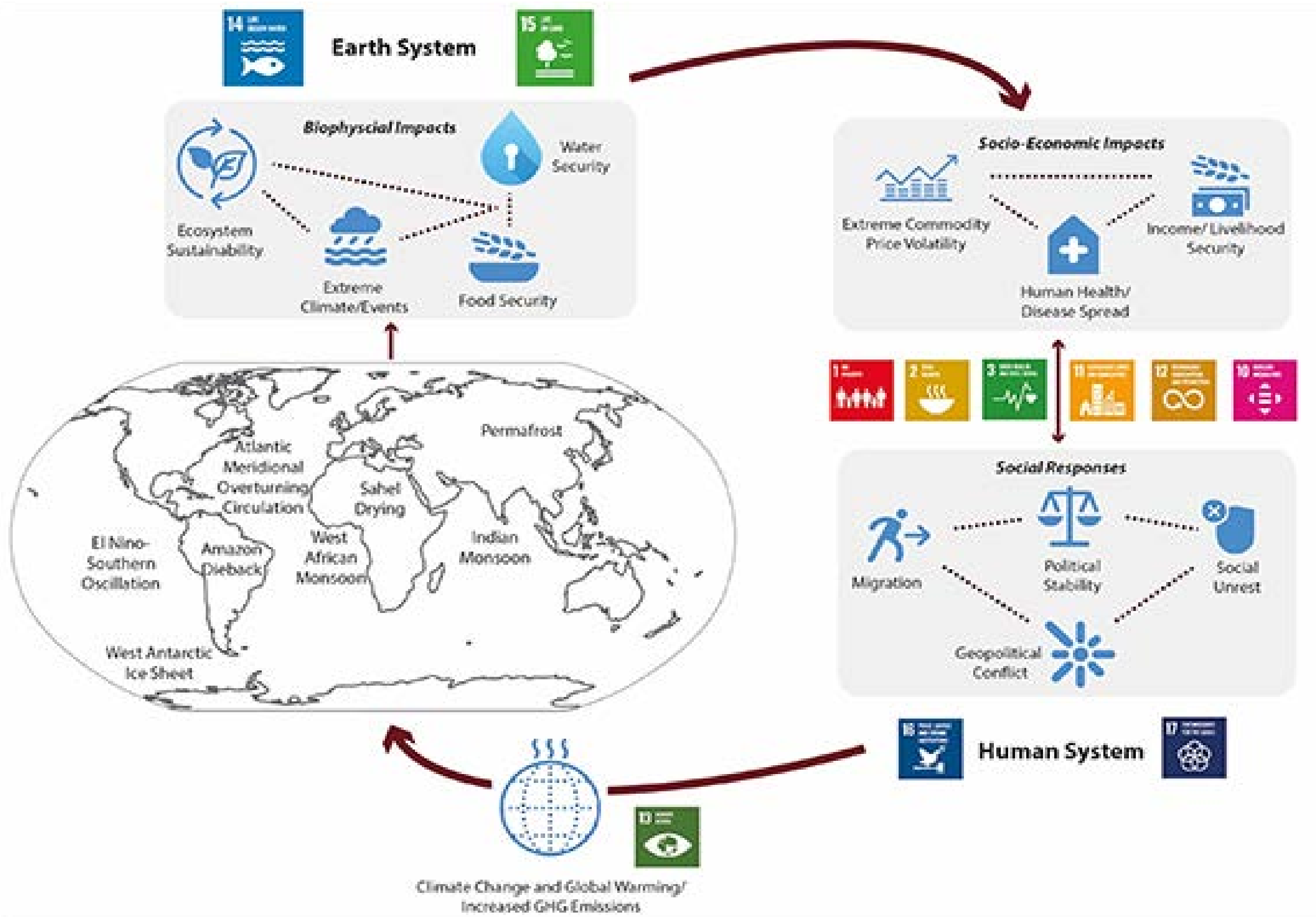

Figure 4.5.2: Possible interactions and cascades between the Earth system and the human system. Pathways can cascade into the human system inducing economic and social responses and potentially tip some social subsystems into a different state, such that they can increase or mitigate global warming and potentially affect further tipping elements via positive or negative feedbacks. More responses and interactions are likely than shown here which interact with the SDGs.(Franzke et al., 2022).

Chapter 4.6 Risks, equity and justice in the governance of positive tipping points

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Summary

Earth system tipping points pose existential threats to current and future generations. Those least responsible for causing them are often most at risk. Positive tipping points (PTPs) have the potential to beneficially transform societies, but they carry their own risks. positive tipping points should not perpetuate or create unjust or inequitable outcomes. For example, in our urgency to transition to electric vehicles, the demand for more cobalt and lithium to produce batteries should not come at the expense of creating sacrifice zones and destroying communities elsewhere in the world. Consideration of what needs to change, who is being asked to change, where the change or its impacts will be felt, and by whom, are fundamental questions that require a level of reflexivity and systemic understanding in positive tipping point governance and other decision making.

All actors have a role to play in ensuring that risks, justice, equity and ethics are carefully considered prior to and during interventions. Enabling positive tipping point for radical transformation could benefit from more diverse perspectives to open up solutions, with a particular emphasis on the inclusion of marginalised voices. Taking a precautionary and systemic approach to positive tipping interventions and stepping back to explore all options, not just those appearing to offer a quick fix, should help ensure more socially just and environmentally sustainable outcomes.

Key messages

- Positive tipping point governance that prioritises justice, sufficiency and strong sustainability are the only realistic solutions left. These must be enacted without creating green sacrifice zones where people or places are foregone in the quest for sustainability solutions.
- Considerations of what needs to change, who is being asked to change, where the change or its impacts will be felt, and by whom, require a level of engagement, reflexivity, inclusiveness and systemic understanding.
- All actors can help ensure just and equitable change, especially regarding marginalised voices.

Recommendations

- Public and private finance must provide more supportive and inclusive investment.
- Business should be more proactive in lobbying for and co-creating a level of governance commensurate with the scale and speed of change required.
- Media and other influencers should be aware of political and power dynamics when framing positive tipping point messages.
- Positive tipping point researchers and practitioners must consider diversity and inclusivity and avoid unintended negative consequences when designing projects.

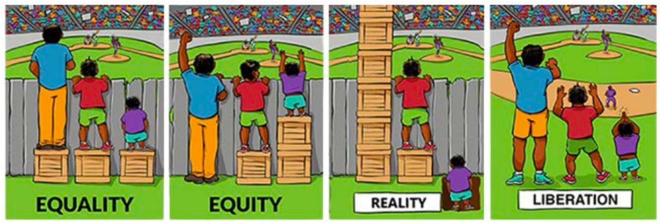

Image Credit: "Artist: Angus Maguire".

4.6.1 Introduction

Humanity faces unprecedented challenges, including climate change, biodiversity loss, inequality and poverty. The Earth system in which human history has played out is fast changing to 'a new climatic regime' (Latour, 2017). In response, diverse groups have called for transformative change, but this is not a simple, inevitable or apolitical process. Orienting complex systems onto more sustainable and socially just trajectories is messy and complicated. As history shows, there are 'dark sides' to transformations, including unintended consequences, losers as well as winners, and the potential for capture by vested interests (Blythe et al., 2018). These risks can be exacerbated in the context of PTPs because interventions designed for exponential and irreversible positive change also carry the risk of exponential and irreversible negative change. A **precautious, considered, systemic approach** is therefore necessary to understand the potential consequences and to whom they might apply. Governance approaches that prioritise climate and ecological stability, equity and justice must anticipate and take steps to avoid perverse outcomes and negative distributional impacts using compensatory and redistributive mechanisms. Trade-offs must be considered, and tough questions asked: What sacrifice zones are being created? Who is likely to occupy them? What forms of vulnerability are being experienced from change? Who is left behind? Here, we understand 'sacrifice zones' as places that include 'extractive zones' – territories, resources and communities that are viewed as extractable and commodifiable by coordinated forms of capitalism (Gómez-Barris, 2017).

Recent United Nations Framework Convention on Climate Change (UNFCC) climate summits have seen an increasing number of calls from climate justice campaigners and representatives of the Global South, including Small Island Developing States, for an acknowledgement of historical damage in the international response to climate change. These are articulated in calls for loss and damage compensation and for reparations (Huq et al., 2013). These calls are supported by the work of climate historians, decolonial critics and others. Together they assert that we cannot hope to agree on climate action if we do not address past injustices and the unequal access to decision making and resources that created the climate and ecological crisis and which continue to shape intergovernmental responses to it (Moore,2016, Yusoff, 2018, Ghosh, 2021, Bhambra and Newell, 2022). Discussions on tipping points, therefore, must emphasise the plight of the poorest and historically marginalised people, who also face the greatest risks, and must acknowledge the central role of the economy and politics in driving precarity. These past and present injustices create a need for the rebuilding of damaged trust and relationships. For many Indigenous peoples and local communities at the forefront of the climate and ecological crisis, these challenges have become a matter of survival (Gilio-Whitaker, 2019; Whyte 2021). Other important considerations include the rights of future generations and the potential for future harms (Rammelt et al., 2023) as well as a need to consider not just humans, but the rights of all species to exist on a healthy planet (Chapron et al., 2019).

4.6.2 What do we mean by equity and justice?

Earth system justice is conceptualised through multiple approaches to justice including, but not limited to, intragenerational, intergenerational and interspecies justice (Gupta et al., 2023). **Intragenerational justice** refers to relationships between humans rights now and includes justice between states (international), among people of different states (global), and between community members or citizens (communitarian). **Intergenerational justice** examines relationships across generations, such as the legacy of greenhouse gas (GHG) emissions for youth and future people and assumes that natural resources and environmental quality should be shared across generations (Tremmel, 2009). **Interspecies justice** refers more generally to the rights of nature and other species to co-existence on the planet (Harden-Davies et al., 2020) and also counters the idea of human exceptionalism as a lens for thinking through development impacts (Srinivasan and Kasturirangan, 2016). These frameworks can help design just responses to the shifts experienced as we near tipping points, or even help us avoid them all together.

In the context of addressing biophysical tipping points by attempting to enable positive social tipping, a justice lens is critical to ensure that past injustices are not perpetuated in the name of staying within planetary boundaries (Rockström et al., 2023). Attempts to address procedural justice (how processes are designed, who is involved), reparative justice (including recognition of wrongs, restoration where possible and compensation for negative impacts), and distributive justice (or equity) are complicated but important. An Earth system justice approach can promote the fair sharing and management of remaining ecological spaces (Gupta et al., 2022).

4.6.3 Governance of PTPs

Just as is the case for Earth system tipping points (ESTPs), there is no global forum, institution or any other initiative yet established to consider the governance of PTPs. Governance, as defined in Section 3, refers to the rules, regulations, norms and institutions that structure and guide collective behaviour and actions. In addition to state actors at various scales down to city and local government, governance also involves non-state actors from the private sector – business, finance and industry – and from civil society organisations and social movements, including those representing campaigns for environmental and social justice, faith groups and Indigenous peoples. There are well-established international institutions that have sustainability goals: for example, the United Nations Development Programme, the Organisation for Economic Cooperation and Development OECD, the World Economic Forum, and the C40 Cities network. But none of these specifically address the goals, resources or strategies for operationalising PTPs.

4.6.3.1 A polycentric approach to PTP governance

The primary objective of any future system of governance for ESTPs is **prevention**. In contrast, the primary objective of any future system of governance with respect to PTPs in human (social) systems is **promotion**. However, in common with and in coordination with ESTP governance, a clear and persuasive logic and agenda for action, political coalition-building, and a multi-scale or polycentric approach and framework is needed (Ostrom, 2010; Jordan et al., 2018). A **polycentric** system is a nested hierarchy of authorities from local to global scales. Each authority has a degree of independence to set and enforce rules. For example, a local authority might be responsible for community-owned energy or food cooperatives; a region might be responsible for new transport and energy infrastructure, or for supporting and reskilling workers in a just transition; each nation might continue being responsible for setting GHG emissions targets and implementing plans to meet them, as they are now. These authorities would also interact, learn from each other, and coordinate efforts to ensure that, collectively, the global goals – for example, net-zero (GHG) emissions by 2050, or 50 per cent fewer people in poverty by 2030 – are achieved (Elsässer et al., 2022).

4.6.3.2 Making the case for PTP governance

The case for inclusive global governance of PTPs needs to be made. Some might question the need, given that action is being taken without it: solar and wind power and battery technology are on exponential growth paths that will disrupt the global electricity sector within this decade (Bond et al., 2023; Nijsse et al., 2023); sales of Electric Vehicles (EVs) are growing exponentially in leading markets and approaching tipping points in others (Meldrum et al., 2023); the technology exists to transform the environmental performance of agriculture and food systems, for example in the use of green ammonia for fertilisers, or the manufacture of alternative proteins for food (Meldrum et al., 2023; FOLU 2021). The potential for some of these solutions to perpetuate inequitable and unjust outcomes, such as green sacrifice zones, should, however, be of great concern, building the argument for an **inclusive governance system** to ensure that risks are accounted for and that the marginalised have political voice and agency. There is also positive movement in climate commitments. Net-zero decarbonisation targets, which no country in the world was thinking about 10 years ago, have now either become legally binding or have been pledged in 96 countries, representing almost 80 per cent of global GHG emissions (WRI, 2023). Some countries have shown it is possible to reduce emissions while continuing to grow their economies – known as absolute decoupling – even taking offshored production into account (Ritchie, 2021). But the rate at which this is happening is still far too slow (Vogel and Hickel, 2023). Revisiting these approaches and **how they are governed with just PTPs in mind** is therefore necessary.

Others might accept the need for governance in principle, but argue that we currently do not have enough empirical evidence to meaningfully influence PTPs in many systems. In addition, some might question the feasibility of PTP governance. Sovereign actors have strong interests in accelerating the transition to a sustainable, post-carbon future – in theory, this is a positive-sum game that everyone can win, not a zero-sum game (Wright, 2001). So far, however, the system of governance that has developed is highly complex and cumbersome and has barely begun to consider tipping points in natural systems, let alone in human systems. Structural impediments like vested interests, perverse incentives, competitive market dynamics and legacies of colonialism all offer significant barriers that need to be overcome (Scoones et al., 2020, Ghosh, 2022). A recent assessment of the 17 United Nations Sustainable Development Goals (SDGs), which are meant to be achieved by 2030, concluded that none were on track. It calculated that, on current trends, the world in 2030 would have 575 million people living in extreme poverty, 600 million facing hunger, the +1.5°C 'safety limit' for global heating would be beyond reach, and gender equality would take another 300 years (United Nations, 2023).

We understand these reservations and complexities. Nevertheless, we believe that a global effort to accelerate systemic change – implied in a PTP's discourse – is urgently needed. This is not to claim that all action and progress requires global agreement – far from it. A lot has already been achieved at the national level and much more is possible through small group coalitions of nations and climate clubs (4.4.2.5). But some things do require global cooperation and governance, such as the 1.5°C/well-under-2°C limit of the Paris Agreement. Meeting that limit, justly and in time, will also require some global governance, cooperation and coordination of effort. We cannot avoid difficult, contentious decisions, and we do not have time to postpone them any longer. ESTPs are fast becoming a real threat, so the only way to prevent them is through transformative change, which may include successfully enabling PTPs. Incremental, linear change is no longer an option.

Inclusive global governance to promote PTPs is therefore necessary for essentially the same reason that it is necessary to prevent and adapt to ESTPs – because it requires collective action across diverse actors. Deep emissions cuts and climate-resilient development that prioritises risk reduction, equity and justice would be much easier to achieve with a level of global cooperation that creates 'a sense of collective responsibility and action' (Wiedmann et al., 2020, p. 7), as evidenced in global environmental agreements. This is a complex and delicate task that ultimately relies on finding an inclusive narrative that encourages ambition and enables action. However, the former 'peaceful and reassuring' (Bonneuil and Fressoz, 2016) narrative based on consensus, voluntary measures, efficiency gains and the gradual decoupling of emissions is insufficient to meet the globally agreed +1.5°C limit (Meinhauser et al., 2022). If we are serious about navigating towards a more just, equitable and sustainable future, radical solutions that prioritise staying within Earth system boundaries, implementing Earth system justice, ensuring sufficient, and strong sustainability are the only realistic solutions left (Gupta et al., 2023; Rockström et al., 2023 ; Newell et al., 2021; Trebeck and Williams, 2019; Raworth, 2017; Haberl et al., 2020; Steinberger, Lamb, and Sakai, 2020).

Looking just at the climate issue and the avoidance of 'negative' ESTPs, what matters for sustainability is the **aggregate amount** of GHG pollutants and other drivers/stressors **from all sources**, and the speed at which they can be safely and justly phased out. The development of new technologies, of net-zero policies, or of absolute decoupling, are important parts of that aim and, at least for richer countries, might be achievable without international cooperation. However, cooperation can accelerate these changes, as shown in economic modelling of Electric Vehicle (EV) mandates, for example (Lam and Mercure, 2022). The key question is whether collectively they can amount to deep enough, wide enough, or fast enough change. As previously mentioned in relation to energy systems, rapid growth in wind and solar capacities have led to a reduction in fossil fuel demand in Organization for Economic Cooperation and Development (OECD) countries, but not globally, as other nations have increased fossil fuel demand. Success is ultimately measured in terms of the speed at which we globally phase out GHG emissions and the extent (or 'depth') to which we apply principles of Earth system justice while doing so (Gupta et al., 2023). Following the X-curve framework, this requires rapidly transitioning away from the current energy system dependent on fossil fuels in an equitable fashion – a just transition – while rapidly transitioning towards an alternative system that is also more equitable and just and respects 'safe' Earth system boundaries.

4.6.3.3 Metaphorical scales of justice

Tensions between these two imperatives – the need for speed and for depth – support arguments for the governance of PTPs (Anderson et al., 2023). On the one hand, one might argue that since every additional tonne of GHG emissions adds to the toll in human lives, and every additional fraction of a degree of global heating multiplies threats, including the threat of ESTPs, then speed equals justice. On the other hand, if the speed of decarbonisation and the upscaling of technological change are the sole considerations, this offers carte blanche to the most powerful, dominant actors to restructure the new post-carbon economy in ways that maintain existing power, gender, and socioeconomic inequalities (Newell, Geels and Sovacool, 2022; Gabor, 2023).

In this scenario, while tipping points in technological innovations alone could conceivably save more lives, they could also squander a unique opportunity for greater inclusivity and 'depth' in the redesign of society along more equitable lines (Leach and Scoones, 2006). For example, instead of an energy system composed of a massively distributed network of community-owned and managed cooperatives offering very low-cost, secure energy, we may enter a post-carbon society in which a small number of oligopolistic energy suppliers continue to command a high price and reap extortionate profits (Stone et al., 2021; Hoffman and High-Pippert, 2005). One example that demonstrates governance that respects both the need for renewables and concern over ownerships and consolidation – speed as well as depth – can be found, for example, in Denmark, where there is a minimum requirement of 20 per cent community ownership of wind power (May and Diesendorf, 2018).

Using metaphorical scales of justice, some might judge that a rapid transition that saves more lives (speed) outweighs the benefits of a longer struggle for energy democracy (depth) – where, for the sake of argument, these are perceived to be mutually exclusive. But these and other competing claims for justice at least deserve due consideration. Governments themselves are highly unlikely to initiate action that disrupts dominant systems of power in which they are key players. Instead, governance that encompasses other, non-state actors, beginning with social movements and civil society, would be expected to initiate these forms of political struggle (Smith et al., 2020).

4.6.4 Blind spots, risks and unintended consequences

Climate policymakers and other influential actors tend to focus on the more technological, less politically risky or contentious aspects of climate governance (Patterson et al., 2018). Justice and ethical implications of policies and other actions also tend to be ignored, leading to blind spots in who loses and in the assumptions made when labelling change as 'positive'.

Whether in their eagerness to accelerate technological fixes, or a desire to maintain unanimity, momentum and political will, negotiators have sometimes been tempted to ignore or dismiss normative dimensions of climate policy and the possibility of unintended social consequences (Klinsky et al., 2017). However, all actors in the process – from scientists to world leaders – need to be careful to avoid today's solutions becoming tomorrow's harms. This is especially true when considering interventions designed to trigger exponential rates of positive social change or quick 'techno-fixes' (Sovacool, 2021). Solar radiation management is one such intervention that has already clearly been stated as not a feasible or just option for PTPs in this report, but there are other techno-fixes that could result in an equally exponential increase in unintended negative consequences. It is thus imperative that all actors take responsibility to include a justice framing, acknowledging potential risks, when referencing positive social tipping points as solutions to the ongoing climate and other social-ecological crises.

Some 'positive' interventions for climate impact mitigation and adaptation can also have unintended consequences and pose ethical challenges. In particular, they require careful consideration about what is 'positive' and about any attempt to intervene in systems that can never be fully understood.

4.6.4.1 Examples of negative consequences

An example of the risks associated with the quest for PTPs is the transition to a renewable energy economy that is driving the growing demand for batteries, solar panels and digital devices, all of which require mining of lithium, cobalt and other rare Earth minerals (Dutta et al., 2016). While this creates economic benefits for mining communities, it can also produce negative ecological, economic and social impacts in the near, medium and long-term (Soto, Hernandez and Newell, 2022; Manzetti and Mariasiu, 2015). The industrial mining sector has been accused of supporting state violence and corruption, polluting ecosystems and failing to relieve poverty, while the informal mining sector is known for ignoring occupational safety and health standards and human rights concerns (Calvão et al., 2021;Sovacool, 2019).

Other prominent examples of unintended consequences have been documented for a variety of cases linked to positive interventions for sustainability. Some large-scale renewable and bioenergy projects have resulted in significant local opposition (Cavicchi, 2018) and have resulted in the displacement of Indigenous peoples and local communities (UNPFII, 2023: Zurba and Bullock, 2020) as well as impacting small-scale fisheries (Beckensteiner et al., 2023). Other potential impacts of such renewable energy projects include deforestation (Kraxner et al., 2013), biodiversity losses (Pedroli, et al., 2013) and competition for land and water resources; which can also lead to food insecurity (Hasegawa et al., 2020). Decarbonisation of the built environment, particularly the housing stock, has resulted in health impacts from poor indoor air quality, and fuel poverty (Davies and Oreszczyn, 2012). Carbon offset markets have driven afforestation in open ecosystems, resulting in negative impacts on biodiversity, ecosystem function and livelihoods (Bond et al., 2019).

4.6.5 Winners and losers: sacrifice zones

PTP interventions that succeed in accelerating a reduction in GHG emissions by, for example, a switch to renewable electricity using batteries that require rare earth metals, or by expanding natural carbon sinks, could reduce access to food, livelihoods and land for vulnerable communities (Mehrabi et al., 2018). The tendency for PTPs to benefit some people while (intentionally or unintentionally) excluding others creates sacrifice zones.

Well-intentioned interventions have the potential to put severe pressure on lands held by Indigenous and marginalised communities and reshape their ecologies into 'green sacrifice zones' by reproducing a form of climate colonialism in the name of just transitions. (Zografos and Robbins, 2020).

Climate colonialism involves addressing the climate crisis through the continued domination of less powerful countries and peoples through initiatives that intensify foreign exploitation of their resources or undermine the sovereignty of Indigenous peoples and local communities (Sultana, 2022). Green sacrifice zones refer to ecologies, places and populations that will be severely affected by the sourcing, transportation, installation and operation of solutions for powering low-carbon transitions, as well as end-of-life treatment of related material waste (Zografos and Robbins, 2020). Such sacrifice zones are not random, but carefully chosen within a power dynamic of colonial paradigms, worldviews and technologies that reduce life by equating it to a mere capitalist resource (Gómez-Barris, 2017).

The root causes of harm are often obscured when Western knowledge and technocratic interventions are prioritised over others, but there is an emerging governance of the impacts of loss and damage that need to be taken up by decision makers (Jackson et al., 2023). One critical aspect is to shift the focus away from individual action (Newell et al., 2021,) that places responsibility for change on those with least agency, and towards tackling the 'polluter elite' (Kenner, 2019; Wiedmann et al., 2020) and the infrastructure of high-impact sectors such as food and energy production, transport and housing that, combined, comprise about 75 per cent of total carbon footprints (Newell et al., 2021). In this, the PTP agenda could have a significant impact if it maintains reflection on who is being asked to change and why in order to drive nonlinear change.

4.6.6 Self-determination for the Global South

The capacity of the Global South and other marginalised communities to self-determine (make choices without the coercion of more powerful actors) has sometimes been undermined in diverse ways. Firstly, some commentators (e.g. Lyon and Maxwell, 2011) have argued that sustainability has been used as a cynical ploy: Western-led development frameworks and models have promised to uplift 'vulnerable' communities with payments for ecosystem services (Bottazzi et al., 2018), carbon trading and renewable energy projects, but which result in weakening or disregarding local structures and creating new structures and feedbacks that largely benefit developers. Evidence of the controversial impacts on local communities of Payment for Environmental Services (PES) has only recently become well known (Bottazzi et al., 2018). Although farmers have in some cases been willing to accept compensation for their nature conservation efforts in PES programmes (Geussens et al., 2019), such payments are often too little to cover their social and economic opportunity costs (Hayes et al., 2022; Vedeld et al., 2016). As a consequence, a system is created which promotes new forms of value (often monetary at the expense of other values), and which exacerbates existing inequalities and injustices and cultivates division within communities.

Creating a more decolonised future in the PTP or transformation landscape involves allowing local voices and capacities to surface in and by themselves (Scoones et al., 2015), to self-organise, self-determine and design changes as they see and need them (Rocha et al., 2022). By decolonial, we refer to the move away from the colonial worldview that anything differing from a Eurocentric worldview is inferior, marginal, irrelevant or dangerous (Santos, 2021) towards an appreciation of multiple temporalities, knowledges and praxes of living (emphasising the prefix 'de' rather than the prefix 'post') (Mignolo, 2021).

Supportive resources should also be chosen according to local needs and framings without stringent, unrealistic or exploitative terms and conditions. It is important to note that resources may come from various sources, ranging from development aid to compensation for historic damage (e.g. loss and damage payments due to historic GHG emissions), to payments for whatever international donors care about, such as investments in conservation projects.

Investment in a specific agenda for the 'global good' – for example, to avoid negative tipping points – cannot be undertaken at the expense of local needs without commensurate change in the behaviours of wealthy countries whose development has largely led to this crisis. (Hickel et al., 2022; Hickel and Slamersak, 2022).

As recommended by Obura et al., (2023), any positive changes in the human-nature discourse must uphold and respect local rights and voices, and as such enable agency to undertake the necessary changes.

With this in mind, there needs to be a deeper engagement to understand what kinds of information, knowledge and interventions can lead to PTPs that are truly equitable and spread the burden of change to those who have benefited most from the current system, rather than further marginalising the most vulnerable. Scientists, practitioners and their organisations who create decision making tools and solutions need to explicitly recognise the risks and trade-offs associated with them. The power dynamics of global models of carbon sequestration – for example, tree planting schemes – that impact local people and communities need to be carefully considered (Pereira et al., SI). It is of critical importance for researchers and practitioners working on positive and negative tipping points to reflect on how their findings might be used by other actors to drive agendas that aim to dismantle an unjust system (Engler and Engler, 2021). This requires a decolonisation of the solution space of what is needed to address tipping points. Space for alternatives that do not come from a Western-dominated perspective needs to be opened up and imaginations engaged (Pereira et al., SI; Yusoff and Gabrys 2011). In particular, there needs to be an openness to alternative economic models based on regeneration beyond growth.

4.6.7 Forms of equity and justice

Governance needs to go beyond over-simplistic, quantitative indicators, such as counting how many trees have been planted and where. It needs to acknowledge the rights, values, visions, knowledge and needs of local communities in policies: **recognitional equity**. It also needs to ensure an inclusive and participatory decision-making process: **procedural equity** (Bennett, 2022). Earth system, biodiversity and wellbeing outcomes (as well as potential harms) should be balanced: **distributional equity**. The interests of disadvantaged or marginalised groups need to be safeguarded, including nonhuman species and ecosystems: **environmental equity**. Leadership from, and participation with, local communities should be fostered and improved to allow local engagement in management activities: **management equity**. Emphasis should also be placed on qualitative factors such as equity and justice of protected areas: **contextual equity** (Pickering et al., 2022). Failing to address any of these dimensions may result in reproducing historical injustices and simply 'kick the tipping point down the road'.

4.6.8 Implications for practice

We close by recommending some practical implications for different change agents.

4.6.8.1 Policymakers

Governments must step up to address inequality through improved legal and fiscal policy (Green, 2021). Domestic fiscal policy needs to subsidise or compensate lower-income households for the higher costs that accompany regulations like carbon pricing, emissions trading and new standards. Failure to do so could set off a cascade of unintended consequences and increase poverty, inequality and other impacts like popular protest and political instability. Legal mechanisms to ensure procedural, reparative and distributive justice are also imperative. PTPs require intervening in complex systems that we do not fully understand. Policymaking therefore needs to become more flexible and anticipatory, and include the ability to correct for unintended consequences. Such anticipatory governance mechanisms could include ringfencing funding to support unintended consequences as well as ongoing review of policy interventions to assess their effectiveness and equity and allow for a change of direction if necessary. Policy and governance actors attracted to positive social tipping interventions should also recognise that research is constantly updating and so there is a need to be aware of hidden assumptions, biases and potential for backfires, rebounds and other unwelcome results (Sterman, 2002).

4.6.8.2 Finance

Investments need to guide sectors along more sustainable and equitable pathways rather than fuel unsustainable business models, working conditions and use of resources – for example through the coupling of public incentives and improved working conditions (Jouffray et al., 2019). Divesting from companies that are seen to be complicit in transgressing planetary boundaries, such as oil majors and powerful cattle lobby groups in the Brazilian Amazon (Piotrowski, 2019) has the potential to reshape the business environment towards more equitable practices. Another area where investments could leverage PTPs is in the shift away from car dependency, particularly for those living in densely populated metropolitan areas, whose health and life expectancy would benefit from improved air quality and pedestrian safety (Rionfrancos et al., 2023). 4.3.2 on transport and mobility systems discusses efforts to avoid demand for material-intensive mobility and shift to more active modes of travel. Finally, finance has the opportunity to redistribute money to vulnerable regions and intervention spaces like mitigation, adaptation, loss and damage, and biodiversity (4.4.3). Currently there is highly uneven access to credit and capital to bring about more transformative change. Such reconfiguration of finance flows needs to be undertaken with full consideration of the impact that such investments would have, not just on financial returns, but also on social and environmental outcomes.

4.6.8.3 Business

Businesses are part of social-ecological systems, not separate from them, and so business needs to recognise that the only way to avoid negative tipping points is through active interventions to change the current system. This requires strong regulation of the access and financial power that incumbents have over political systems to enable a space for transformative change. Businesses that want to be leaders in a more sustainable and equitable future should also encourage the redirection of financial resources towards enabling PTPs and away from sectors causing the most harm. For example, they should support moves to redirect the US$11m per minute currently being spent on fossil fuel subsidies towards improved access to renewable energy for poorer communities (McCulloch, 2023).

4.6.8.4 Media and discourse

Media, and all climate communicators, must be alert to the competing ideologies, values and systems of power that affect which messages are communicated and how that message is interpreted by different communities. This is particularly relevant in relation to the language of 'positive' and 'negative' tipping points, which can imply a universality of effect that is insensitive to the diverse experiences and responsibilities of different communities. Knowledge does not automatically lead to enlightened action (Norgaard, 2011). Certain facts and emphases – for example, emphasising the risks of climate breakdown rather than the co-benefits of climate action – may serve to further entrench dismissive perceptions of climate change (Bain et al., 2012). There is therefore a need to shift away from linear, 'information-deficit' models of communication towards values-inclusive, reflective and creative dialogues (Gaertner and Dovidio, 2014; Stirling, 2010). Communication strategies should be tailored to and co-produced with the communities they are seeking to engage (Wang et al., 2020). Media and communication organisations must not see themselves as neutral information transmitters, but as actors in a complex, nonlinear system that is entangled with issues of knowledge and power.

4.6.8.5 Researchers

More inclusive global research needs to be undertaken that reflects on the justice and risk aspects of tipping points. Scientists have an agenda-setting function and a breadth of expertise that will be invaluable in navigating the science-policy interface and solving complex problems like tipping points. Greater diversity in terms of cultural, religious, ethnic, gender, background and discipline of researchers is needed. Place-specific information and experience is often lacking as a lot of research is concentrated in high-income countries. In order to harness relevant positive tipping opportunities, researchers and practitioners need to understand diverse living realities and interact with actors outside of their professional 'bubbles' (Bentley et al., 2014).

Avoiding diverse harms requires a broad range of experience and expertise, and an acknowledgement of the need for plural approaches not only within academic disciplines, but also of diverse knowledge systems beyond academia.

(Tàbara et al., 2022). By being more mindful about inclusiveness, research can bring about more procedural justice into research through participatory co-design, action research and humility on the part of researchers. Diversity and inclusivity of research teams – within and beyond academia – are needed to help find solutions to tipping points that do not exacerbate existing inequities and inequalities.

4.6.8.6 Embrace creative co-production

The effectiveness of literature, film and art in promoting ethical responses to climate change is increasingly being recognised (James, 2015; Weik von Mossner 2017; Galafassi et al., 2018): 'The arts have an ability to communicate the vulnerability and sensitivity of climate issues that other channels may lack' (Holmes 2020, P.10). The arts also offer models for empowering communities to create their own narratives and contextualise tipping points in relation to their own systems of value. These can help to imagine and articulate alternative imaginaries of change: 'from what is to what if?' (Hopkins, 2019).

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