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IIASA Expert Workshop on System Dynamics of Social Tipping Points

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BACKGROUND NOTE

This background note introduces key terms, concepts, and literature to provide a common basis of understanding on which we can build during the workshop. We also suggest references as further reading for those interested. In particular we will be substantially drawing on Otto et al. (2020) in the workshop. If you do not have access to any of the papers referenced, please let us know and we can share them.

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KEY CONCEPTS AND TERMS

1. **Tipping points describe critical thresholds in complex systems that - if crossed - can lead to qualitatively different system states.**
   1.1. A tipping point is crossed when a small perturbation triggers a large system response driven by positive (reinforcing) feedbacks that dominate system dynamics and propel change (Sharpe & Lenton, 2021).
   1.2. Tipping processes occur in systems near to a critical threshold in one or more control variable (e.g., global mean temperature in the climate system). Crossing the critical threshold 'tips' the system into a qualitatively different state (Lenton, 2020).
   1.3. Tipping points are typically reached when boundary conditions are 'forced' in a direction that weakens negative (balancing) feedbacks or strengthens positive (reinforcing) feedbacks (Sharpe & Lenton, 2021).
   1.4. In general, tipping processes are irreversible as they fundamentally change the structure and intrinsic functioning of a system (Tàbara et al., 2018).

2. **Research on tipping points and processes has a long history in both natural and social sciences, although with different terminology (Milkoreit et al., 2018).**
   2.1. Recent interest in climate tipping points has identified critical thresholds that - if passed - could lead to nonlinear changes in the earth system (e.g., shutting off of ocean circulation systems, dieback of Amazon rainforest, decay of Greenland ice sheet) (Lenton et al., 2008).
   2.2. The impact of these climate tipping points are increasingly analysed as low-probability high-consequence risks to the global economy, strengthening the economic case for stringent climate policy (Dietz et al., 2021; Lontzek et al., 2015).
   2.3. Tipping processes in socioeconomic systems are distinct from those in earth systems as: (1) they involve human agency; (2) they involve social network-related change mechanisms and do not have to physically co-occur; (3) they have more complex sets of interacting drivers and mechanisms, and do not have a single control variable (Winkelmann et al., 2022). Social tipping processes also tend to occur over shorter timescales and at more local or regional scales (Figure 1).
   2.4. Recent interest in social tipping points is distinguished from wider research on socio-technical transition and societal transformation by its interest in small triggers resulting in accelerated change to a qualitatively different system state.

3. **Social tipping processes describe how social, political, economic or technological systems can move rapidly into a new system state or functioning.**
   3.1. Social tipping processes are emergent properties of complex social systems that include both human capacities and structural conditions. Social tipping processes allow for rapid transformation in individual and collective practices (Tàbara et al., 2018).
   3.2. In social systems, transitions that are initially reversible may become irreversible over time as new feedbacks emerge, such as the political difficulty of reversing support for a new technology sector with associated jobs (Sharpe & Lenton, 2021).
   3.3. Positive feedback effects that act as amplifiers in social systems include learning curves and network externalities (in technological systems), or self-fulfilling beliefs, norm cascades, and bandwagon effects (in social systems) (Farmer et al., 2019).
   3.4. In technological systems, diffusion is characterised by increasing returns to scale leading to tipping processes when dynamics becomes self-reinforcing.
      3.4.1. Returns to scale result from learning-by-doing, economies of scale, network externalities, complementary technologies and infrastructures, and standardisation (Grübler et al., 1999).
      3.4.2. The inflection point on diffusion S-curves is associated with higher system reactivity as system members are sensitive to change, and cascades of change occur (Rogers et al., 2005).
   3.5. In social systems, social norms pass tipping points when the benefit of shifting to a new norm outweighs the conformity incentive to stick to the old norm.
      3.5.1. Preferences for risk or conformity are heterogeneous. Instigators of change face a first mover dilemma as the costs of nonconformity are high, even if norm change is beneficial. But societal preferences change over time (e.g., awareness builds, demographic shifts). Once a critical number abandon the old norm, conformity incentives shift to the new norm (Andreoni et al., 2021).
      3.5.2. 'Critical mass' describes how a committed minority triggers tipping processes in a social system when the minority view becomes rapidly accepted. Centola et al. (2018) estimate critical mass thresholds from 10-40% of a population depending on the change process involved.
      3.5.3. Applied to socio-political processes, social change in the form of shifting public opinion, increased activism, expression of public concern, and new coalitions of interest can help punctuate previously sticky political institutions and lead to policy change (Winkelmann et al., 2022).
      3.5.4.

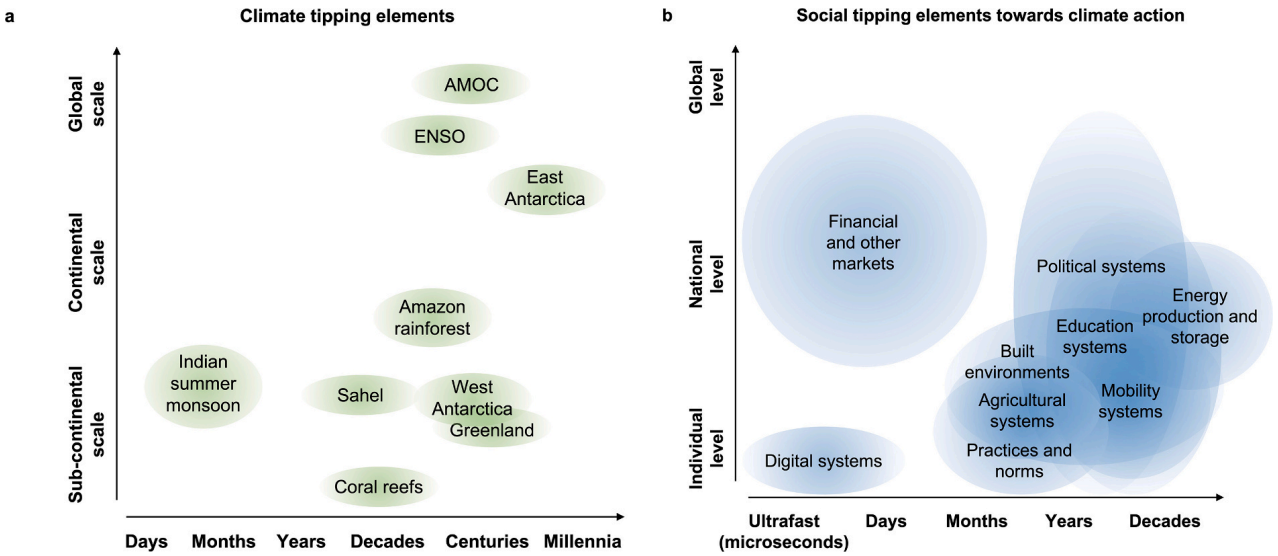

Figure 1. Spatial and temporal scales for climate tipping elements (panel a) and social tipping elements (panel b). Source: Figure 2 in Winkelmann et al. (2022).

DEFINITIONS OF KEY TERMS

*"'**Tipping**' describes the point or threshold at which small quantitative changes in the system trigger a non-linear change process that is driven by system-internal feedback mechanisms and inevitably leads to a qualitatively different state of the system which is often irreversible" (Milkoreit et al., 2018).*

*"A '**social system**' can be described as a network consisting of social agents (or subsystems) embedded within a social-ecological environment. Such a social system is called a '**social tipping element**' if under certain critical conditions, small changes in the system or its environment can lead to a qualitative macroscopic change, typically via cascading network effects such as complex contagion and positive feedback mechanisms … The resulting transient change process is called the '**social tipping process**'" (Winkelmann et al., 2022).*

Following Otto et al. (2020) and Winkelmann et al. (2022), in this background note we use the following terminology:

- **'Social tipping elements'** = socioeconomic systems in which tipping can occur.
- **'Social tipping interventions'** = active changes made to socioeconomic systems to trigger tipping.
- **'Social tipping processes'** = positive feedback mechanisms in the tipping of a socioeconomic system.
- **'Social tipping dynamics'** = drivers, mechanisms and outcomes of tipping in a socioeconomic system.

SOCIAL TIPPING ELEMENTS AND INTERVENTIONS

4. **Social tipping elements have been identified in social, political, economic and technological systems, along with interventions for activating them.**
   - 4.1. Otto et al. (2020) identify six key social tipping elements which are subdomains of socioeconomic systems where a disruptive change can take place and lead to rapid decarbonization. They also identify social tipping interventions that can trigger such disruptive changes.
     - 4.1.1. *Energy production and storage:* Increasing the relative price of clean energy technologies through subsidy programs and decentralized production can trigger reinforcing feedback mechanisms in the energy system for a rapid transition towards clean technologies.
     - 4.1.2. *Human settlements:* Choosing clean technologies in new urban infrastructure triggers both cost reductions and consumer interest in environmental technologies and can lead to rapid decarbonization.
     - 4.1.3. *Financial markets:* Divestment from fossil fuel assets can rapidly reinforce investors' belief in the risks of carbon-intensive assets and lead to a shift of financial support from fossil fuels to clean technologies.
     - 4.1.4. *Norms and value systems:* Advocacy by a small group of thought leaders can lead to a large fraction of the population recognising the immoral character of fossil fuels, hence a shift in norms and values, and increased pressure on policymakers to restrict the use of fossil fuels.
     - 4.1.5. *Education system:* Coverage of the causes and effects of climate change in school curricula leads to increased public knowledge and awareness, which can trigger sustained widespread engagement in climate action.
     - 4.1.6. *Information feedbacks:* Both in the public consumption domain and in financial markets, disclosure of information on carbon emissions can trigger rapid behavioural change. Corporate disclosures are expected to enhance investors' belief in the risks of carbon-intensive assets. Disclosure on consumer products can induce widespread engagement in climate action and lifestyle changes.
   - 4.2. Social tipping processes resulting from interventions in social tipping elements can be represented as causal loop diagrams. Figure 2 provides an example using the *Education system* example from Otto et al. (2020) which is labelled as STE5.

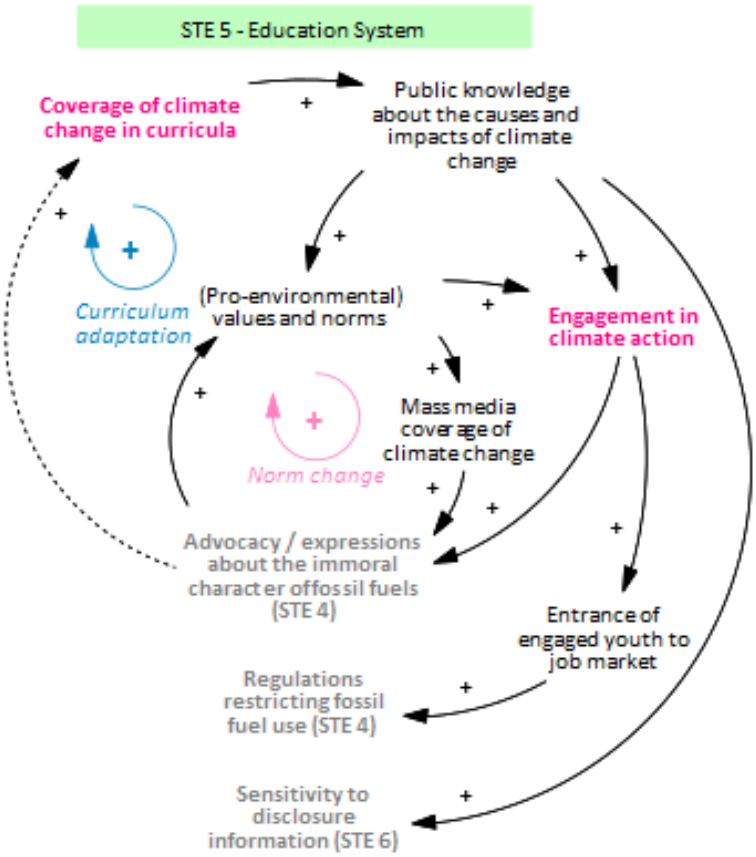

Figure 2: Causal loop diagram representing social tipping dynamics in the education system on climate action, norms and values, and climate policies. Arrows with polarity signs indicate a causal relationship and coloured circles represent feedback mechanisms. Derived by Sibel Eker based on information in Otto et al. (2020).

5. Social tipping interventions identify actions or policies that can push a system towards triggering tipping processes.

5.1. Farmer et al. (2019) define 'sensitive intervention points' as relatively small changes that can trigger a large change in systems that sit at a critical threshold or boundary between qualitatively different types of behaviour. Interventions can be 'kicks' or 'shifts'. Kicks push the system onto a new trajectory without changing underlying system dynamics (e.g., financial disclosure, technology investment, political mobilisation). Shifts change the rules of the system and its dynamics (e.g., institutional structures) (Farmer et al., 2019).

5.1.1. *Financial disclosure:* Small changes in financial accounting rules or disclosure guidelines on climate risk can rapidly reduce the value of fossil-fuel assets, increase the financial risk of exploiting fossil reserves, increase the credibility of net-zero targets, and so reduce the supply of fossil-fuel energy.

5.1.2. *Technology investments:* Targeted investments to stimulate learning effects and economies of scale can help clean energy technologies outcompete fossil-fuel incumbents, make the energy transition profitable, neutralise resistance to change, and so make rapid decarbonization cheaper and easier. See also (Ives et al., 2021).

5.1.3. *Political mobilization:* Small groups of influencers or 'political entrepreneurs' can mobilise the silent pro-climate majority, coordinate public support, raise political salience, reduce the costs of advocacy, recruit more supporters, and so create enabling conditions for strong policy action.

5.1.4. *Institutional structures:* New institutions, laws, and organisations can stabilise, strengthen, and sustain long-term commitment and political action on climate change through monitoring,

reporting, compliance, and ratcheting ambition (e.g., 2008 UK Climate Change Act, 2015 Paris Agreement).

5.2. Sharpe and Lenton (2021) show how targeted investment and pricing policies in small groups of countries can bring clean technologies below the threshold of cost-parity with fossil fuel technologies, and trigger shifts in global markets.

5.3. Similarly, Climate Action Tracker (2019) identify targeted investments, incentives, and regulations to drive down the costs of energy storage (for grid integration of intermittent renewable power), electric vehicles, and decarbonised cement production.

5.4. Winkelmann et al. (2022) discuss how the Fridays For Future school strikes have triggered a strong response in the German socio-political system evident in an upward shift in public concern, strong electoral support for Greens, and a new federal climate neutrality law that could potentially lead to wider shifts in the EU climate policy landscape.

5.5. Similarly, Smith et al. (2020) caution against an over-reliance on policy actions as social tipping interventions. They argue that civil society and social movements create the constituency for government-led interventions (which are effect not cause). They also emphasise the importance of local clusters of strong ties for building and expanding social mobilisation.

6. Interventions to trigger tipping processes can also be articulated as broad strategies for system change.

6.1. Meadows (1999) ranks twelve 'leverage points' to intervene in a system in order of effectiveness. These include: changing the structure of material stocks and flows (#10); adding information feedbacks on system functioning (#6); and changing the goal of the system (#3).

6.2. Chan et al. (2020) characterise eight leverage points for transforming socio-ecological systems: (1) visions of a good life; (2) total consumption and waste; (3) latent values of responsibility; (4) inequalities as a means towards change; (5) justice and inclusion; (6) distant externalities from local actions - e.g., trade, commodity demand, supply chains; (7) responsible technology, innovation and investment; (8) education and knowledge generation and sharing. (See Figure 3).

6.3. These coincide with the social tipping elements and interventions identified by Otto et al. (2020). For example, the decentralisation of energy production, the use of clean technologies in urban infrastructure, and fossil fuel divestment, all influence the inflows and outflows of energy infrastructure stocks. In contrast, shifting norms and values change the goals of the system, and carbon disclosures trigger information feedbacks (Otto et al., 2020).

6.4. Chan et al. (2020) also identify five strategies for intervening on leverage points for societal transformation: (a) incentives and capacity building; (b) coordination across sectors and jurisdictions; (c) pre-emptive action; (d) adaptive decision-making; (e) environmental law and implementation. (See Figure 3).

INTERACTIONS BETWEEN SOCIAL TIPPING PROCESSES

7. Social tipping dynamics propagate through interconnected systems.

7.1. Sharpe and Lenton (2021) emphasise how tipping processes in interconnected systems can propagate up through scales of impact. They call this an "upward-scaling tipping cascade".

7.2. Figure 4 provides an example for electric vehicles (EVs). If the EU, China and California (which account for 50% of new car sales) were to follow Norway-style policies for reducing the cost premium of EVs relative to conventional vehicles, this could trigger an irreversible shift in the global vehicle market.

7.3. Otto et al. (2020) highlight potential interactions between the six social tipping elements (socioeconomic subsystems) that can further accelerate tipping dynamics. For example, Figure 2 shows how more emphasis on climate change in the *Education system* (STE5) can lead to wider advocacy activities that trigger shifts in *Norms and value systems* (STE4), that in turn demand for more climate change coverage in school curricula. Increased climate change knowledge through the education system also creates a higher sensitivity to carbon-emission disclosures on consumer products and triggers *Information feedbacks* (STE6).

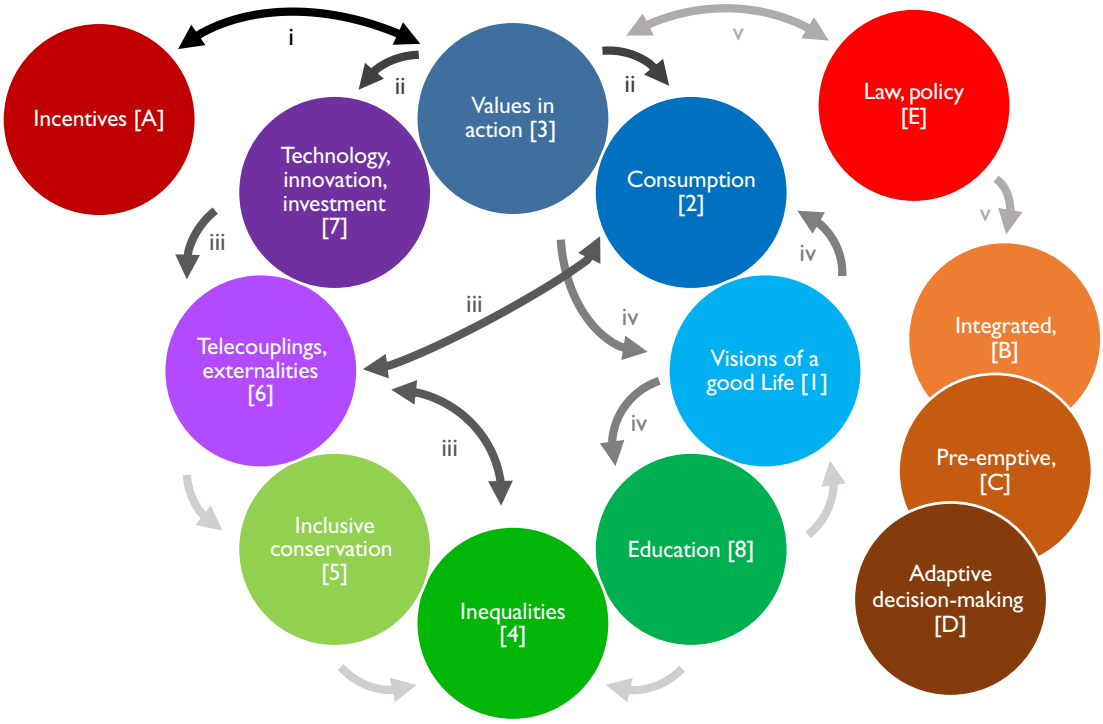

Figure 3. Strategic levers (A-E) acting on interacting leverage points (1-8) to co-produce global sustainability in socio-ecological systems. Source: Figure 4 in Chan et al. (2020).

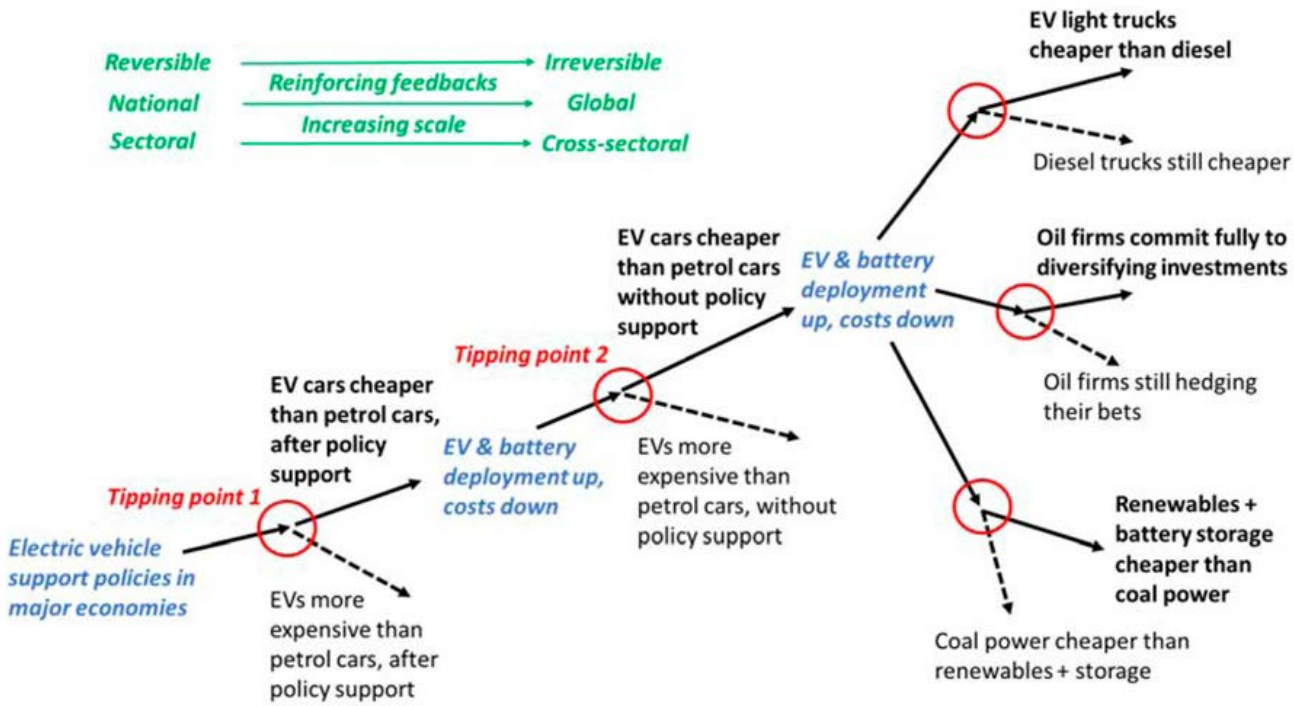

Figure 4. Upward-scaling tipping cascades. Source: Figure 2 in Sharpe & Lenton (2021).

INDICATORS OF SOCIAL TIPPING PROCESSES

8. Indicators can track progress towards triggering social tipping processes.

8.1. Early warning indicators of approaching tipping points in the earth system include a slowing recovery rate to perturbations (Lenton, 2020). A similar approach could be applied to social systems by monitoring temporal volatility in indicators of the incumbent regime, such as share prices of fossil energy majors or automotive firms (Sharpe & Lenton, 2021).

8.2. Online social media platforms also provide real-time data on topics of interest to large populations worldwide that can be used to track public opinion and action (Eker et al., 2021).

8.3. As a caveat, social tipping processes have a more complex set of drivers, mechanisms, and outcomes than climate tipping processes so early-warning indicators with well-defined critical thresholds for tipping are not as readily available (Winkelmann et al., 2022). Evaluation of tipping processes can likely only be made in hindsight through specific process tracing of specific triggering events and amplifying mechanisms.

9. Cost parity between clean energy alternatives and fossil-fuel incumbents is a key indicator of potentially rapid system change.

9.1. Climate Action Tracker (2019) identify potential transformation points in the energy system, with trackable indicators for each:

9.1.1. Cost parity between renewable electricity generation+storage and new or existing fossil-fuel assets.

9.1.2. Up-front cost parity between electric vehicles and conventional vehicles (or electric vehicles find large-scale niches such as cities).

9.1.3. Up-front cost parity between building new net-zero energy homes and building inefficient homes.

9.1.4. Cost-parity between direct air capture and storage of CO_2 and mitigation options in hard-to-abate sectors (e.g., aviation).

9.1.5. Availability of competitive zero-carbon high-intensity heat for industrial processes.

9.1.6. E-bikes become the norm for intra-urban mobility.

References

Andreoni, J., Nikiforakis, N., & Siegenthaler, S. (2021). Predicting social tipping and norm change in controlled experiments. *Proceedings of the National Academy of Sciences, 118*(16), e2014893118. https://doi.org/10.1073/pnas.2014893118

Centola, D., Becker, J., Brackbill, D., & Baronchelli, A. (2018). Experimental evidence for tipping points in social convention. *Science, 360*(6393), 1116-1119. https://doi.org/doi:10.1126/science.aas8827

Chan, K. M. A., Boyd, D. R., Gould, R. K., Jetzkowitz, J., Liu, J., Muraca, B., Naidoo, R., Olmsted, P., Satterfield, T., Selomane, O., Singh, G. G., Sumaila, R., Ngo, H. T., Boedhihartono, A. K., Agard, J., de Aguiar, A. P. D., Armenteras, D., Balint, L., Barrington-Leigh, C., Cheung, W. W. L., Díaz, S., Driscoll, J., Esler, K., Eyster, H., Gregr, E. J., Hashimoto, S., Hernández Pedraza, G. C., Hickler, T., Kok, M., Lazarova, T., Mohamed, A. A. A., Murray-Hudson, M., O'Farrell, P., Palomo, I., Saysel, A. K., Seppelt, R., Settele, J., Strassburg, B., Xue, D., & Brondízio, E. S. (2020, 2020/09/01). Levers and leverage points for pathways to sustainability. *People and Nature, 2*(3), 693-717. https://doi.org/10.1002/pan3.10124

Climate Action Tracker. (2019). *Transformation points: Achieving the speed and scale required for full decarbonisation* (CAT Decarbonisation Series: Transformation Points, Issue. climateactiontracker.org

Dietz, S., Rising, J., Stoerk, T., & Wagner, G. (2021). Economic impacts of tipping points in the climate system. *Proceedings of the National Academy of Sciences, 118*(34), e2103081118. https://doi.org/10.1073/pnas.2103081118

Eker, S., Garcia, D., Valin, H., & van Ruijven, B. (2021, 2021/06/22). Using social media audience data to analyse the drivers of low-carbon diets. *Environmental Research Letters, 16*(7), 074001. https://doi.org/10.1088/1748-9326/abf770

Farmer, J. D., Hepburn, C., Ives, M. C., Hale, T., Wetzer, T., Mealy, P., Rafaty, R., Srivastav, S., & Way, R. (2019). Sensitive intervention points in the post-carbon transition. *Science, 364*(6436), 132-134. https://doi.org/10.1126/science.aaw7287

Grübler, A., Nakićenović, N., & Victor, D. G. (1999, 1999/05/01/). Dynamics of energy technologies and global change. *Energy Policy, 27*(5), 247-280. https://doi.org/10.1016/S0301-4215(98)00067-6

Ives, M. C., Righetti, L., Schiele, J., De Meyer, K., Hubble-Rose, L., Teng, F., Kruitwagen, L., Tillmann-Morris, L., Wang, T., Way, R., & Hepburn, C. (2021). *A new perspective on decarbonising the global energy system.* (Report No. 21-04).

Lenton, T. M. (2020). Tipping positive change. *Philosophical Transactions of the Royal Society B: Biological Sciences, 375*(1794), 20190123. https://doi.org/doi:10.1098/rstb.2019.0123

Lenton, T. M., Held, H., Kriegler, E., Hall, J. W., Lucht, W., Rahmstorf, S., & Schellnhuber, H. J. (2008). Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences, 105*(6), 1786. https://doi.org/10.1073/pnas.0705414105

Lontzek, T. S., Cai, Y., Judd, K. L., & Lenton, T. M. (2015). Stochastic integrated assessment of climate tipping points indicates the need for strict climate policy. *Nature Climate Change, 5*(5), 441-444. https://doi.org/10.1038/nclimate2570

Meadows, D. (1999). *Leverage Points: Places to Intervene in a System*.

Milkoreit, M., Hodbod, J., Baggio, J., Benessaiah, K., Calderón-Contreras, R., Donges, J. F., Mathias, J.-D., Rocha, J. C., Schoon, M., & Werners, S. E. (2018, 2018/03/01). Defining tipping points for social-ecological systems scholarship—an interdisciplinary literature review. *Environmental Research Letters, 13*(3), 033005. https://doi.org/10.1088/1748-9326/aaaa75

Otto, I. M., Donges, J. F., Cremades, R., Bhowmik, A., Hewitt, R. J., Lucht, W., Rockström, J., Allerberger, F., McCaffrey, M., Doe, S. S. P., Lenferna, A., Morán, N., van Vuuren, D. P., & Schellnhuber, H. J. (2020). Social tipping dynamics for stabilizing Earth's climate by 2050. *Proceedings of the National Academy of Sciences, 117*(5), 2354-2365. https://doi.org/10.1073/pnas.1900577117

Rogers, E. M., Medina, U. E., Rivera, M. A., & Wiley, C. J. (2005). Complex adaptive systems and the diffusion of innovations. *The Innovation Journal: The Public Sector Innovation Journal, 10*(3), 1-26.

Sharpe, S., & Lenton, T. M. (2021, 2021/04/21). Upward-scaling tipping cascades to meet climate goals: plausible grounds for hope. *Climate Policy, 21*(4), 421-433. https://doi.org/10.1080/14693062.2020.1870097

Smith, S. R., Christie, I., & Willis, R. (2020). Social tipping intervention strategies for rapid decarbonization need to consider how change happens. *Proceedings of the National Academy of Sciences, 117*(20), 10629. https://doi.org/10.1073/pnas.2002331117

Tàbara, D. J., Frantzeskaki, N., Hölscher, K., Pedde, S., Kok, K., Lamperti, F., Christensen, J. H., Jäger, J., & Berry, P. (2018, 2018/04/01/). Positive tipping points in a rapidly warming world. *Current Opinion in Environmental Sustainability, 31*, 120-129. https://doi.org/https://doi.org/10.1016/j.cosust.2018.01.012

Winkelmann, R., Donges, J. F., Smith, E. K., Milkoreit, M., Eder, C., Heitzig, J., Katsanidou, A., Wiedermann, M., Wunderling, N., & Lenton, T. M. (2022, 2022/02/01/). Social tipping processes towards climate action: A conceptual framework. *Ecological Economics, 192*, 107242. https://doi.org/10.1016/j.ecolecon.2021.107242