4. Tipping Points In Transitions Of Socio-Economic Systems

Franziska Mey[1]
Johan Lilliestam[2]

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4.1. Introduction

There is a common understanding among academics of the need for a large-scale disruptive and rapid change to limit global warming to 1.5°C through reaching 80% zero-emission energy by 2030 and 100% by 2050.[4] Shifting to a new system is a central focus of transition research and has been on the agenda

1. *Institute of Sustainable Advanced Studies. E-mail:* Franziska.Mey@iass-potsdam.de

2. *Institute for Advanced Sustainability Studies, Leader of the research group Energy Transitions and Public Policy; University of Potsdam. E-mail:* Johan.Lilliestam@iass-potsdam.de

3. Mey, Franziska and Lilliestam Johan, *Deliverable 3.1: Policy and governance perspectives on tipping points - A literature review and analytical framework* (Potsdam: Institute for Advanced Sustainability Studies, 2020).

4. Indra Overland and Benjamin K. Sovacool, 'The misallocation of climate research funding,' *Energy Research and Social Science* 62 (April 2020): 101349. https://doi.org/10.1016/j.erss.2019.101349

for several decades. Sustainability transitions refer to large-scale societal changes deemed necessary to solve 'grand societal challenges.' A key concern of transition research is to understand and explain how to achieve radical systemic change in a way that major societal functions are maintained.[5] Indeed, in the face of global challenges, incremental improvements are no longer appropriate.[6] Instead, rapid and complete systemic transitions are required.[7]

Indeed, past transitions have demonstrated that social systems can rapidly tip into entirely different states. At some point in time, complex systems that developed over decades and centuries experienced a 'tipping point,' changing their trajectories to their current state. A classic example is the transition from horses to today's car-based mode of transport. This mobility change provided a number of benefits such as individual independence, flexibility, and increased range and speed of movement. The downside comes with air pollution, the dependency on petrol and diesel, and lock-in effects in shaping our living infrastructure, economies, and social interactions. Another example is the development of the textile industry in Germany (similarly to other western countries). This sector had reached a peak in the 1960s with almost 700,000 workers. Yet, processes of globalisation and deindustrialisation contributed to a significant decline in local production over the following decades. The textile industry faced a significant rise in competition (e.g., low labour costs) and international division of labour, tightened environmental and social regulations, and changing consumer behaviour. Today, almost all German textile

5. Frank. W. Geels, 'A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies,' *Journal of Transport Geography* 24 (September 2012): 471–82. https://doi.org/10.1016/j.jtrangeo.2012.01.021; Derk Loorbach, Niki Frantzeskaki, and Flor Avelino, 'Sustainability Transitions Research: Transforming Science and Practice for Societal Change,' *Annual Review of Environment and Resources* 42 (October 2017): 599–626. https://doi.org/10.1146/annurev-environ-102014-021340; Jochen Markard, Rob Raven, and Bernhard Truffer, 'Sustainability transitions: An emerging field of research and its prospects,' *Research Policy* 41, no. 6 (July 2012): 955–67. https://doi.org/10.1016/j.respol.2012.02.013

6. Jonathan Köhler, et al., *A research agenda for the Sustainability Transitions Research Network.* (Sustainability Transitions Research Network Working Group, 2017). http://t.ly/Xl5G

7. Jochen Markard, Frank W. Geels, and Rob Raven, 'Challenges in the acceleration of sustainability transitions,' *Environmental Research Letters* 15, no. 8 (August 2020): 081001. https://doi.org/10.1088/1748-9326/ab9468; Daniel Rosenbloom, et al., 'Why carbon pricing is not sufficient to mitigate climate change—and how "sustainability transition policy" can help,' *Proceedings of the National Academy of Sciences of the United States of America* 117, no. 16 (April 2020): 8664–68. https://doi.org/10.1073/pnas.2004093117

production has moved to develop countries leaving less than 30,000 employees only in the high-end textile section.[8] These examples indicate that tipping points can be found in various transition processes, yet what specifically triggers these processes remains ambiguous.

Transitions are influenced and often determined by deliberate political, economic, and civil society actions. However, there is a paucity of information regarding concrete sustainability interventions or leverage points that bring the required impact.[9] This is the case for transitions that are 'moving away' from something while less clearly moving towards something new.[10] For instance, the phase-out of coal can be a disruptive process specifically for localities with a strong dependence on the extractive industries, which produces winners (somewhere else and possibly locally) and losers (mainly locally).

We know that societies affected by such transitions sometimes enter a negative spiral, despite the will and actions of decision-makers on different levels to do the contrary. The economic downturn caused by the loss of a core economic activity causes social problems, which exacerbates the economic downturn, and so on. In other cases, regions may face initial problems as the core activity disappears, but they manage to enter a new, positive development trajectory: some interventions or developments trigger new activity, innovation, and growth, which in turn, causes social improvements and more economic activity, and so on. Hence, in some cases, regions spiral down, whereas, in others, they enter a new virtuous circle: at some point in time, following some interventions, regions tip to either positive or negative socio-economic patterns.

A better understanding of what makes these regions tip towards either positive or negative development trajectories is a prerequisite to enabling a 'just

8. Andreas Stamm, et al., *Soziale und ökologische Herausforderungen der globalen Textilwirtschaft* (Bonn: Deutsches Institut für Entwicklungspolitik gGmbH, 2019).

9. Christian Dorninger et al., 'Leverage points for sustainability transformation: a review on interventions in food and energy systems,' *Ecological Economics* 171 (May 2020): 106570. https://doi.org/10.1016/j.ecolecon.2019.106570

10. Benjamin K. Sovacool, 'How long will it take? Conceptualizing the temporal dynamics of energy transitions,' *Energy Research and Social Science* 13 (March 2016): 202–15. https://doi.org/10.1016/j.erss.2015.12.020

transition' as defined in the Paris Agreement.[11] Here, we propose an analytical framework and a set of indicators for identifying tipping points in socio-technical and socio-economic systems. For this, our guiding research question is 'what indicators will help to identify the moment ex-post when a system tips to a low carbon trajectory?'

4.2. Tipping Points

This section addresses a brief overview of the transition literature and the embedded tipping point research, the generic understanding of tipping points, and the findings of recent investigations for technical, social, and ecological tipping points.

Most likely, everyone has experienced a tipping point of some sort in their life since the latter can both apply to microscopic or large-scale situations. The media, popular writers, and many academics regularly refer to the term 'tipping points' when indicating a significant threshold. The concept was popularised by Gladwell, drawing on epidemic theory suggesting that little measures can result in contagious and fast-spreading changes in their environment once a certain threshold is reached.[12] He offered a number of examples of tipping points including the cleaning up of the New York subway that led to a significant drop in the crime rate in the city in the early 1990s. This involved small and seemingly trivial actions like removing graffiti and prosecuting fare evasion which were addressed as expressions of disorder that invited much more serious crime: reducing these small nuisances had big effects on local crime rates. Another example of the phenomenon is the increasing dissatisfaction with the economic situation in the former German Democratic Republic provoking mass protests and ultimately the collapse of the country. Another case in point could be the high number of people simultaneously infected with Covid-19 triggering the health systems in some countries to collapse. These examples

11. 'Paris Agreement,' conclusion date: December 12, 2015, United Nations Treaty Series Online, registration no. I-54113. http://unfccc.int/paris_agreement/items/9485.php

12. Malcolm Gladwell, 'The Tipping Point,' *New Yorker*, June 3, 1996. http://t.ly/lJp7

point to a pressing question: 'could we have known these events'? And if yes, by which metrics could we have known – how can we recognise upcoming tipping points?

Tipping Points in Academic Literature

The idea of tipping points, i.e., thresholds, critical junctures, or leverage points, is not new and has been applied in different disciplines to describe the dynamics of significant change.[13] The first academic use of the term tipping point dates to studies of neighbourhood segregation in the US in the 1950s. Mark Grodzins applied the phrase 'tip point' to a critical proportion of non-whites in a neighbourhood above which the fraction of whites precipitously declined to zero.[14] In the following years, the term was further applied and developed by economists and urban sociologists such as Eleanor Wolf, Thomas Schelling, and Jonathan Crane on similar social phenomena.[15] Importantly, Schelling emphasised two key characteristics of a tipping point as being a process that disturbs an original equilibrium and leads to an accelerated and irreversible change.[16]

In the last 15 years, natural scientists have formalised the concept in different disciplines and domains. In this vein, a tipping point is used to refer to a situation in which an ecosystem experiences a drastic shift to a new state causing significant changes to its biodiversity and ecosystem services. In the climate system, it is understood as 'a critical threshold' at which 'a small change in forcing triggers a strongly nonlinear response in the internal dynamics of part of

13. David J. Abson, et al., 'Leverage points for sustainability transformation,' *Ambio* 46, no. 1 (June 2016): 30–39. https://doi.org/10.1007/s13280-016-0800-y; Ruth Collier and David Collier, *Shaping the political arena: Critical junctures, the labor movement, and regime dynamics in Latin America* (Notre Dame: Notre Dame University Press, 2015); Jonathan Crane, 'The Epidemic Theory of Ghettos and Neighborhood Effects on Dropping Out and Teenage Childbearing,' *American Journal of Sociology* 96, no. 5 (March 1991): 1226–59. https://www.jstor.org/stable/2781341; Dorninger et al., 'Leverage points for sustainability;' Donella Meadows, 'Leverage Points Places to Intervene in a System,' accessed March 28, 2022. http://t.ly/eVtx; Paul Pierson, *Politics in time: history, institutions, and social analysis* (Princeton: Princeton University Press, 2004).

14. Mark Grodzins, 'Metropolitan Segregation,' *Scientific American* 197 no. 4 (October 1957): 33–41. https://www.jstor.org/stable/24941940

15. Eleanor P. Wolf, 'The Tipping-Point in Racially Changing Neighborhoods,' *Journal of the American Institute of Planners* 29, no. 3 (1963): 217–22. https://doi.org/10.1080/01944366308978066; Crane, 'Epidemic Theory of Ghettos;' Thomas Schelling, *Micromotives and Macrobehavior* (New York: Norton & Company, 1978).

16. Schelling, *Micromotives and Macrobehavior*.

the climate system, qualitatively changing its future state.'[17] In climate research, these authors introduced the term 'tipping elements' as large-scale components of the Earth system that may pass a tipping point such as the Arctic sea ice and the Greenland ice sheet.[18] This led them to analyse the potential risk of tipping the entire climate system and to highlight the challenges of anticipating these points and consequently, influencing climate policies.

By the same token, economists have also applied this concept. For instance, models have been developed to calculate the risks and costs of tipping points for ecosystems in response to changes in rainfall patterns, depletion of resources, and deforestation, among others. Thus, it has been found that a failure to address them can yield downward spiral situations in terms of the state of marginal sustainability and that interventions, e.g., payments for ecosystem services, are necessary to ensure the continued provision of global benefits from intact ecosystems and avoid tipping into less stable of beneficial natural system states.[19]

Tipping Point Research Embedded in Transition Literature

Over the last decades, the grand societal transitions have been investigated from multiple perspectives. For example, Loorbach, Frantzeskaki, and Avelino identified three major lines of research: the socio-technical, socio-institutional, and socio-ecological.[20] The socio-technical perspective is the most well-established field of transition applied research often through multi-level perspective analysis (MLP) to understand the (historical) emergence and dynamics of socio-technical regimes such as energy, water, and mobility. The second line is the socio-institutional approach where research focuses on formal and informal institutional structures such as regulations, norms, cultures, and practises

17. Timothy M. Lenton, 'Early warning of climate tipping points,' *Nature Climate Change* 1 (July 2011): 202. https://doi.org/10.1038/nclimate1143

18. Timothy M. Lenton, et al., 'Tipping elements in the Earth's climate system,' *Proceedings of the National Academy of Sciences* 105, no. 6 (March 2008): 1786–93. http://dx.doi.org/10.1073/pnas.0705414105

19. Sergio L. Franklin and Robert S. Pindyck, 'Tropical Forests, Tipping Points, and the Social Cost of Deforestation,' *Ecological Economics* 153 (November 2018): 161–71. https://doi.org/10.1016/j.ecolecon.2018.06.003; Rodrigo Harrison and Roger Lagunoff, 'Tipping points and business-as-usual in a global commons,' *Journal of Economic Behavior and Organization* 163 (July 2019): 386–408. https://doi.org/10.1016/j.jebo.2019.05.015; Lenton, et al., 'Tipping elements.'

20. Loorbach, Frantzeskaki, and Avelino, 'Sustainability Transitions Research.'

that involve transitional change. In this light, studies are concerned with the creation and impacts of path dependencies and how these are challenged by social innovations. The third line stresses the interplay between ecological systems and societal contexts resorting to insights from biophysical science. Here, major explanatory frameworks have emerged around the term 'resilience' or 'panarchy,'[21] and the boundaries of ecological systems which are marked by tipping points provoking shifts from one dynamic equilibrium to another.

Research across these three perspectives has emphasised contagious and fast-spreading social and technological change to accelerate global decarbonisation measures.[22] Indeed, applying the analytical lens of tipping points to socio-technical and socio-institutional systems can yield important insights into the general question of what is required to tip a system to a low carbon trajectory. Instead of a large-scale event, it might only need small changes to trigger a positive feedback loop and push a complex system into a new system state – pushing it over a tipping point.[23]

Tipping Points from The Socio-Ecological Perspective

A growing bulk of work linking ecosystems and social science is emerging from the socio-ecological approach of transition research. Here, scholars seek to identify critical thresholds in the interactions between the complex human society and biophysical systems to avoid undesirable transitions. For example, Fernández-Giménez et al. found that Mongolian steppes are close to ecological and cultural tipping points based on an analysis of time series data for climate, vegetation, and livestock and human population. They claimed that

21. Lance H. Gunderson and Crawford Holling, ed. *Panarchy: Understanding transformations in Human and Natural Systems* (Washington: Island Press, 2002).

22. Ilona. M. Otto, et al., 'Social tipping dynamics for stabilizing Earth's climate by 2050,' *Proceedings of the National Academy of Sciences of the United States of America* 117, no. 5 (January 2020): 2354–65. https://doi.org/10.1073/pnas.1900577117; J. David Tàbara, et al., 'Positive tipping points in a rapidly warming world.' Current Opinion in Environmental Sustainability 31 (April 2018): 120–129. https://doi.org/10.1016/j.cosust.2018.01.012; J. David Tàbara, et al., 'On the Discovery and Enactment of Positive Socio-Ecological Tipping Points: Insights from Energy Systems Interventions in Bangladesh and Indonesia,' *Sustainability Science* 17, no. 2 (March 2022): 565–71. https://doi.org/10.1007/s11625-021-01050-6

23. Abson et al. 'Leverage Points for Sustainability;' J. Doyne Farmer, et al., 'Sensitive intervention points in the post-carbon transition,' *Science* 364, no. 6436 (April 2019): 132–34. https://doi.org/10.1126/science.aaw7287; Meadows, 'Leverage Points Places.'

rural-urban migration leads to loss of pastoral cultural and place identity, values, and traditional ecological knowledge. They applied the notion of tipping points as 'reversible and irreversible thresholds, regime shifts, and other long-term system-level changes, regardless of whether these changes are sudden or non-linear.'[24]

This understanding draws on the distinction made by Scheffer et al. between irreversible, catastrophic thresholds, and non-catastrophic thresholds that are potentially reversible.[25] Others have defined the concept more restrictively. Milkoreit et al., for example, see tipping points as moments 'within a socio-ecological system at which a small quantitative change inevitably triggers a non-linear change in the social component of the social-ecological system, driven by self-reinforcing positive-feedback mechanisms, that inevitably and often irreversibly lead to a qualitatively different state of the social system.'[26]

In a more socially-focused research line, the study by Lamberson and Page made the important distinction between direct tips and contextual tips.[27] The former occurs when a gradual change in the value of a variable causes a large discontinuous jump in the future.[28] Nonetheless, the authors particularly highlighted the importance of context tips that often make direct tips possible, for instance, when human rights conditions in a state deteriorate, creating the potential for an uprising. The authors pointed out that such uprising occurs when a gradual change in the value of one variable brings about a discontinuous jump in some other variable of interest – the system may tip, due to an event affecting only a particular part of the system.[29]

24. María E. Fernández-Giménez et al. 'Exploring Linked Ecological and Cultural Tipping Points in Mongolia,' *Anthropocene* 17 (March 2017): 47. https://doi.org/10.1016/j.ancene.2017.01.003

25. Marten Scheffer et al. 'Early-Warning Signals for Critical Transitions,' *Nature* 461 (September 2009): 53–59. https://doi.org/10.1038/nature08227

26. Manjana Milkoreit et al. 'Defining Tipping Points for Social-Ecological Systems Scholarship - An Interdisciplinary Literature Review,' *Environmental Research Letters* 13, no. 3 (March 2018): 10. https://doi.org/10.1088/1748-9326/aaaa75

27. P. J. Lamberson and Scott E. Page, 'Tipping Points,' *Quarterly Journal of Political Science* 7, no. 2 (April 2012): 175–208. https://doi.org/10.1561/100.00011061

28. Ibid.

29. Ibid.

The broader political and socio-economic structures can determine continuity (equilibrium) or change (punctuated equilibrium) and trigger either self-correcting or self-reinforcing feedback loops. A certain alignment, timing, and sequence of developments can create a critical juncture situation and ultimately, influence the outcomes. However, the significance of a critical juncture can only be established ex-post and regarding the specific historical legacy. Junctures are 'critical' because, once an option is selected, this development may become entrenched, locking the system into this particular trajectory and making it hard, or impossible in the short term, to enter a new development trajectory.

Positive Tipping Points and Tipping Interventions

In a distinct line of tipping research, increasing attention has been paid to the role of perception, narratives (discourse), and social capacities. For instance, Russill and Nyssa found that popular use of tipping points originates in a desire to reshape how the public views dangerous climate change.[30] This notion of urgency has been either welcomed (to accelerate action) or criticised. An example of this is Nuttal's work which evaluated the negative perception of 'a point of no return' in the climate discourse as too simplistic and scaremongering.[31] Russill and Nyssa suggested acknowledging the metaphorical character of tipping points and viewing them as change coming from the internal dynamics of a system rather than an external force.[32] This may actually entail that tipping points can be triggered and controlled.

Similarly, Tàbara et al. emphasised the potential influence of tipping points and the change created through conscious and deliberate processes, and hence they can be altered through learning and purposeful actions, for example, articulated in narratives.[33] They posited that there can be positive tipping points which may be understood as 'the moment in which both social and ecological

30. Chris Russill and Zoe Nyssa, 'The tipping point trend in climate change communication,' *Global Environmental Change* 19, no. 3 (August 2009): 336–44. https://doi.org/10.1016/j.gloenvcha.2009.04.001

31. Mark Nuttall, 'Tipping Points and the Human World: Living with Change and Thinking about the Future,' *Ambio* 41, no. 1 (January 2012): 96–105. https://doi.org/10.1007/s13280-011-0228-3

32. Russill and Nyssa, 'The tipping point trend.'

33. Tàbara, et al., 'Discovery and Enactment.'

systems together take new positive and intentional trajectories.'[34] This implies that tipping points can be influenced and brought about through purposeful measures and actions which can have major desirable systemic effects both on individual life trajectories as well as broader systems.

On the other hand, psychology and economic behaviours research has already shown that accumulation of effects due to social contagion, repetitive nudging, or direct intervention can lead to social tipping dynamics.[35] This is suggested in Gladwell's popular example from the New York subway cleaning but also tackled in other examples such as Crane's findings. He determined that a decrease in neighbourhood quality yields a sharp increase in the probability that an individual develops a social problem, namely: an increase in dropouts and teen childbearing rates. This was observed as a contagious dynamic when the number of workers with high-status jobs in the area decreased below 4%.[36]

The foregoing indicates that influencing social tipping points through purposeful interventions could be a way to prevent or avoid negative transition outcomes. An example of this is Otto et al.'s work that concluded that governance and policy interventions play an important role.[37] In this vein, they defined social tipping interventions as directed measures that 'can activate contagious processes of rapidly spreading technologies, behaviours, social norms, and structural reorganisation within their functional domains that we refer to as social tipping elements.'[38] Moreover, they contended that adaptation and deployment of existing clean energy technologies is a key element of the decarbonisation process. They added that a critical condition to trigger the tipping process is the moment when fossil-fuel-free energy production yields higher financial returns than the energy production based on fossil fuels. Interventions in this sense are redirecting national subsidy programmes to renewables

34. Ibid., 4.

35. Crane, 'Epidemic Theory of Ghettos;' Eugen Dimant, 'Contagion of Pro- and Anti-Social Behavior Among Peers and the Role of Social Proximity,' *Journal of Economic Psychology* 73 (August 2019): 66–88. https://doi.org/10.1016/j.joep.2019.04.009; Gladwell, 'The Tipping Point.'

36. Ibid.

37. Otto, et al., 'Social tipping dynamics.'

38. Ibid., 2354.

and low-carbon energy sources or removing the subsidies for fossil-fuel technologies.

In another study, Tàbara et al. found that both hand market-based intervention with robust grassroots institutions and hand small-scale initiatives can trigger positive tipping points and have transformative potential for the lives of rural poor in two case studies in Indonesia and Bangladesh. Based on this case study, they emphasised the need to pay attention to processes of social construction and to time dynamics. The authors particularly highlighted three elements for identifying tipping points: the conditions and capacities for a system to change, significant events or interventions shifting the system towards a different trajectory or systems' configuration, and the ultimate impact and structural effects derived from such transformation.

Concluding Summary

Overall, the literature reveals a great interest in the tipping point concept from different disciplines and research streams with a growing number of emergent frameworks and models. Despite the cacophony of definitions and interpretations, we find three overarching evolving themes:

1) Tipping points are moments of discontinuity occurring within a specific context triggered by the conjunction or alignment of developments (or variables). Thus, the system fundamentally, qualitatively, and irreversibly changes its structure and to a future governed by new feedback.
2) There are desired and undesired tipping points having specific positive or negative consequences for human societies. Yet, undesired tipping points have received more attention in the literature so far.
3) Because tipping points are considered to bring about rapid change, there is a great interest and also need to influence (some) tipping points to accelerate the transformation of socio-economic systems.

4.3. Framework and Indicators

Building on the literature, we understand tipping points as moments of discontinuity in which a given system of reference fundamentally and irreversibly

changes its structure and future dynamics that are determined by context and specific interventions leading to either positive or negative impacts. Therefore, we believe that the added value in recognising tipping points is to determine why and when a system follows one or another trajectory. Likewise, this value befalls understanding the interventions and in which contexts they succeed, tipping a system to a low carbon trajectory.

For this purpose, we suggest a tiered approach comprising three dimensions: tipping impact, tipping context, and tipping interventions. The relationship is that tipping interventions may hit a specific context triggering a tipping point that, in turn, creates a bifurcation for a positive or negative trajectory, which ultimately, changes the context conditions (see FIGURE 3).

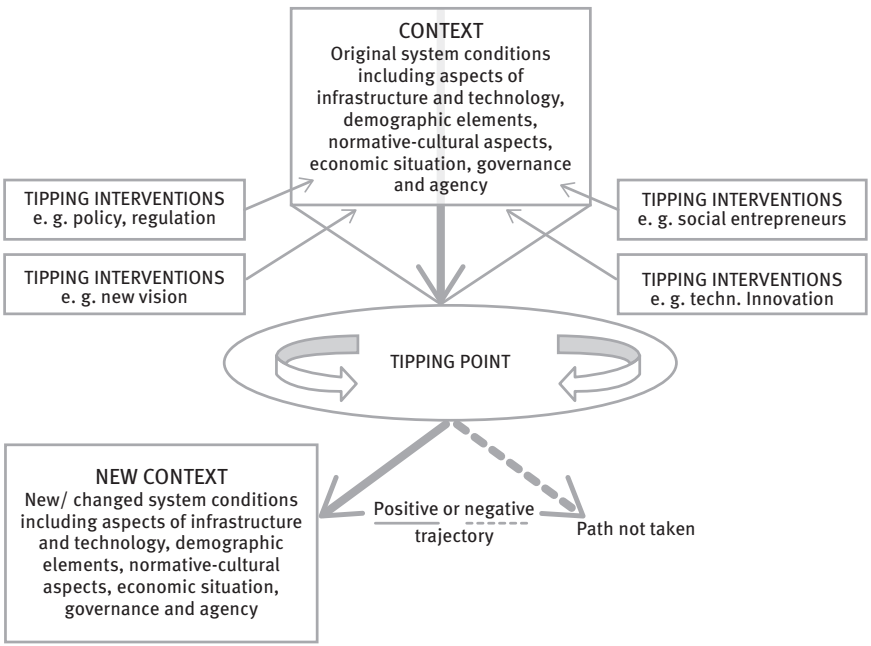

FIGURE 3. Preliminary Tipping Point Analysis Framework

Source: Prepared by authors.

To determine whether a tipping intervention is effective, attention must be paid not only to the intervention but also to the tipping context and desired

impact (i.e., the new context, created by the new trajectory). The three dimensions are discussed below.

Tipping Impact: Positive Tipping Points

Early warnings of tipping points in social, economic, and governmental activities are inherently more difficult to spot.[39] Indeed, just as critical moments or junctures, tipping points can usually only be identified retrospectively in reference to the specific historical legacy or systemic change.[40] This is because tipping points produce specific development paths or trajectories. Furthermore, a change in the structural trends and dynamics of a system can be a measurement of the impact after a tipping point. This involves, for example, the development of a region in regard to economic growth and equality, employment, and migration, among others.

The literature has suggested that there are positive and negative tipping points allowing for qualitatively different developments and impacts over time.[41] As indicated by the adjectives positive and negative, there is a close connection between tipping points and a normative understanding of a desired future state of a system, which implies that what is positive for one actor may be negative for another. For instance, a tipping transition to renewables is positive for environmentalists and the solar industry, but likely negative for the oil industry. However, the term tipping point is also used to describe 'positive feedback processes' that constitute sources of increasing returns and self-reinforcing processes.[42] For example, Lenton et al. refer to tipping points and positive feed-

39. Tim O'Riordan and Tim Lenton, 'Tackling tipping points,' *British Academy Review* 18 (Summer 2011): 21–27. http://bitly.ws/rxL3

40. Giovanni Capoccia, 'Critical junctures and institutional change,' in *Advances in Comparative-Historical Analysis*, eds. James Mahoney and Kathleen Thelen (Cambridge: Cambridge University Press, 2015), 147–79; Collier and Collier, *Shaping the political arena*; Paul Pierson, *Politics in time*.

41. Roope O. Kaaronen and Nikita Strelkovskii, 'Cultural Evolution of Sustainable Behaviors: Pro-environmental Tipping Points in an Agent-Based Model,' *One Earth* 2, no. 1 (January 2020): 85–97. https://doi.org/10.1016/j.oneear.2020.01.003; Tàbara, et al., 'Positive tipping points.'

42. Lenton, et al., 'Tipping elements;' Jochen Markard, 'The life cycle of technological innovation systems.' *Technological Forecasting and Social Change* 153 (October 2020): 119407. https://doi.org/10.1016/j.techfore.2018.07.045; Paul Pierson, *Politics in time*; Gregory C. Unruh, 'Understanding carbon lock-in,' *Energy Policy* 28, no. 12 (October 2000): 817–30. https://doi.org/10.1016/S0301-4215(00)00070-7

back processes triggering changes in the Earth systems such as the melting of the poles' sea-ice.[43]

Similarly, in socio-technical systems, a 'change in gear' is associated with a 'chain reaction of positive feedback loops ... setting in motion a process of cumulative causation.'[44] Institutionalists and economists refer to increasing returns and 'positive feedback' processes as path-dependent processes. This means that a step in a particular direction may generate a positive feedback loop, increasing the pay-off for additional movement in the same direction.[45] On the other hand, the negative feedback loop is associated with a lack of positive feedback or the presence of barriers/forces against change.

In general, positive tipping points can be associated with examples like the approval of the Charter of Human Rights or the abolition of slavery.[46] Kaaronen and Strelkovskii highlight that it is important for sustainability transitions to leverage social systems into tipping points, where societies exhibit positive-feedback loops in the application of sustainable practise including behaviour and cultural traits.[47] In a socio-technical system, the production and storage of energy is a key tipping element.[48] In this case, a positive tipping point constitutes the endogenous and rapid transition to renewable energy sources.[49]

Positive tipping points in a socio-economic system can be related to a positive trajectory in regard to livelihoods and configuration of the domestic economies as well as education, resources, and migration. For example, Tàbara found that a

43. Lenton, et al., 'Tipping elements.'

44. Staffan Jacobsson and Volkmar Lauber, 'The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology,' *Energy Policy* 34, no. 3 (February 2006): 260. https://doi.org/10.1016/j.enpol.2004.08.029

45. Douglass C. North, *Institutions, Institutional Change and Economic Performance* (Cambridge: Cambridge University Press, 1990); Douglass C. North, 'Economic Performance Through Time,' *American Economic Association* 84, no. 3 (June 1994): 359–68. https://www.jstor.org/stable/2118057; Paul Pierson, 'Increasing Returns, Path Dependence, and the Study of Politics,' *American Political Science Review* 94, no. 2 (June 2000): 251–267. https://doi.org/10.2307/2586011; Richard W. Scott, *Institutions and Organizations: Ideas, Interests, and Identities*, 4th ed. (Thousand Oaks, California: SAGE Publications, Inc., 2014).

46. Tàbara, et al., 'Positive tipping points.'

47. Kaaronen and Strelkovskii, 'Cultural Evolution.'

48. Otto, et al., 'Social tipping dynamics.'

49. Tàbara, et al., 'Positive tipping points.'

combined approach of introducing solar home systems, capacity building, and social entrepreneurship in Bangladesh might trigger systemic effects and lead to many other positive effects on education, use of time and resources.[50] We suggest that positive tipping points in socio-economic systems bring qualitative improvement to individual or community life which includes higher (or not reduced) income, better (or not impaired) health, education, and local economic development.

Nevertheless, there are challenges in measuring impact indicators. Firstly, it is necessary to capture the timing of change which requires comparable and long-term data series. Obtaining these for quantitative data could be easier (yet not always), while qualitative data is harder to collect for longer-term developments. Secondly, systemic changes are subject to individual and collective perception and influence the labelling of a certain tipping point into positive or negative. For instance, the reunification in Germany was a significant tipping point in the lives of East-Germans (less so for West-Germans) and the long-run effects have been perceived very differently depending on individual (or community) situations. In addition, data about the different perceptions could be more difficult to obtain. Thirdly, the importance of a tipping point might only be determined in the long term, which will have a direct impact on selecting a timeframe for analysis. Fourthly, tipping points are not necessarily 'points' but can also be stretches of time during which sequences of events unfold. Put it simple, the complexity of social systems can make it challenging to identify causality and datasets for measurement.

Tipping Context

As illustrated in FIGURE 3, the impact of a tipping point is understood as a fundamental intended or unintended change in the (initial) context of a system, recognising that transitions are non-linear and involve context-dependent evolutionary processes with emergent properties.[51] Hence, explaining tipping

50. Tàbara, et al., 'Discovery and Enactment.'

51. Bruno Turnheim, et al., 'Evaluating sustainability transitions pathways: Bridging analytical approaches to address governance challenges,' *Global Environmental Change*, 35 (November 2015): 239–53. https://doi.org/10.1016/j.gloenvcha.2015.08.010

points requires the analysis and description of the broader context of the system. For example, industrial change in coal-phase out regions comprises economic and technical processes, but also political and cultural processes. Drawing on the triple embeddedness framework (TEF) of industrial change, industry actors are embedded in two selection environments (economic and socio-political) and structured by field-specific institutions.[52] Building on sociological and institutional theories,[53] the TEF also highlights the relevance of norms, beliefs, and interpretation as well as the identities of the actors involved. To illustrate this, the meaning associated with 'coal' (as in mining or power plants) as a source of something positive (e.g., economic growth, employment, and prosperity) or something negative (e.g., high pollutants, stranded assets, and drivers of climate change) can be an indicator of the transformative capacity of a region. Meaning and interpretation feed into narratives or visions that are the articulated form of plausible futures and may lead to the emergence of the desired outcomes.[54]

In order to understand the changes that happen in a socio-economic system we suggest investigating the following elements:

- Infrastructure and technology: What are the dominant physical and institutional arrangements in the region, e.g., roads, technology, and educational infrastructure?
- Demographics: Who lives in the region? What are their occupations?
- Normative-cultural aspects: What does the majority think about their region and the subject 'coal'? What are dominant and emerging narratives, frames, and visions?

52. Bruno Turnheim and Frank W. Geels, 'The destabilisation of existing regimes: Confronting a multi-dimensional framework with a case study of the British coal industry (1913–1967),' *Research Policy* 42, no. 10 (December 2013): 1749–7. https://doi.org/10.1016/j.respol.2013.04.009; Bruno Turnheim and Frank W. Geels, 'Regime destabilisation as the flipside of energy transitions: Lessons from the history of the British coal industry (1913–1997),' *Energy Policy* 50 (November 2012): 35–49. https://doi.org/10.1016/j.enpol.2012.04.060

53. Anthony Giddens, *The Constitution of Society: Outline of the Theory of Structuration* (Berkeley: University of California Press, 1984); Scott, *Institutions and organizations*.

54. Tàbara, et al., 'Discovery and Enactment.'

- Economic aspects: What are the local economic situation and dependencies? What are the human and social resources including individual income, poverty rates, GDP, skills, and expertise?
- Governance and agency: How is the region governed? Who are the relevant regional actors and what are their agendas? What is the level of social cohesion?

Tipping Interventions

What social tipping points – either positive or negative – often have in common is that they modify the opportunity space for action, modes of interaction, and the degrees of freedom of the agents within that system.[55] These changes are (often) triggered by deliberate small or larger interventions that might cause tipping points and eventually, social spreading effects. These interventions can come from government (policy intervention), industry (innovations), or social entrepreneurs (cultural, social, or economic intervention). For example, the introduction of the German Renewable Energy Act (EEG) triggered the growth of renewable energy in Germany and also led to substantial system responses in form of self-reinforcing market growth and cost improvement internationally.[56]

A key question for transition research is 'What the kinds of potential tipping interventions can bring about to pursue desired futures?' In this sense, Otto et al. posit small and big interventions producing small effects (i.e., changes in individual life trajectories) or large effects (i.e., broader system changes) (see TABLE 7). Hence, tipping points and tipping interventions can occur at many levels, including at the very micro-sociological one.[57]

TABLE 7. Examples of Intervention-And-Effect Relationships

55. Ibid.

56. Jacobsson and Lauber, 'Politics and policy;' Gregor Kungl and Frank W. Geels, *The Destabilisation of the German Electricity Industry (1998–2015)* (Stuttgart: University of Stuttgart, 2016). http://t.ly/Zfgb

57. Tàbara, et al., 'Discovery and Enactment.'

Intervention type	Small effect	Big effect
Small intervention	Incremental change for emission reduction through local climate policy. Unionised deals with mining companies for workers' compensation, further training, and ensuring workers are not neglected in the phase-out process e.g., in the Spanish transition deal.	Tipping effect for cost reduction of renewable energy from the German EEG so that PV becomes cheaper than coal power.
Big intervention	Inefficient interventions, e.g., the implementation of the European Carbon Emission Trading Scheme, leading to a marginal reduction of greenhouse gas emissions.[58] Potentially: The 2018 German Coal Commission, assigning a significant amount of money (€44 billion) for a relatively small remaining mining workforce and affected communities, and to compensate power mining companies for shutting down before 2038.	Potentially: big effect for reducing carbon emission by removing all government subsidies for fossil fuels industries Potentially: European Green Deal - Platform on Coal and Carbon-Intensive Regions – to ensure that these regions are supported in the transition period

Source: Adapted from Otto et al.[59]

In coal-phase out regions, interventions such as the abrupt closure of a coal mine, the introduction of a sustainable future vision, or policy support for diversifying the local economy can trigger social dynamics provoking either positive or negative tipping points. For example, Spain is in the process of phasing out its entire coal production after a landmark deal of €250,000,000 was

58. Anthony Patt and Johan Lilliestam, 'The Case against Carbon Prices,' *Joule* 2, no. 12 (December 2008): 2494–98. https://doi.org/10.1016/j.joule.2018.11.018

59. Otto, et al., 'Social tipping dynamics.'

struck between the government and unions in 2018, that money being invested in mining regions over the next decade.[60] Although the phase-out had already started in the 2000s, the closing of the industry (which has been ultimately effective) was a major disruption leading to a drastic reduction in employment and production levels. The mitigation measures adopted by the government to mitigate the negative impact on the affected zones through early retirements, and local infrastructure development have been less effective.[61]

Vis-à-vis the discussed above, we suggest investigating tipping interventions as deliberate actions from local, regional, and national actors. Doing so would allow the analysis of how actors seek to influence their socio-economic context through the introduction of new narratives, policies and regulations, and the creation of social networks.

4.4. Summary and Indicators

This chapter provided a preliminary analysis framework to investigate tipping points, their impact, context, and interventions in socio-technical and economic systems. Still, identifying social tipping points is a work in process. Thereby, we would like to conclude with a list of indicators to help identify them based on the three dimensions. It is relevant to note that much more theoretical and empirical work needs to be done from a transdisciplinary perspective for understanding how positive systemic changes can be triggered in deliberate and empowering modes by key agents in specific social circumstances.

Tipping points can be (mainly) identified ex-post in reference to fundamental and irreversible changes in the structure and dynamic of the socio-economic system. The following list of indicators is complemented by our suggestion on how they can be evaluated, if they potentially contribute to a positive or negative trajectory and if they can actually indicate a tipping point event.

60. Pablo Del Río, *Coal Transition in SPAIN* (IDDRI and Climate Strategies, 2017). https://doi.org/10.2523/94173-MS; Arthur Neslen, 'Spain to close most coalmines in €250m transition deal,' *Guardian*, October 26, 2018. https://t.ly/ntO5

61. Lucía Benavides, 'Spain's coal miners continue to wait for their country's "Green New Deal"', *World*. August 16, 2019. https://t.ly/ibVZ

!) Impact indicators: In order to identify positive or negative tipping points, we suggest investigating significant changes in structural trends and dynamics of:

- Population and migration (e.g., gender, education level, and age).
- Employment and unemployment rate.
- Income levels.
- GDP.

We see value in capturing all quantitative indicators over a time span of at least 30 to 50 years. The longer the timeframe the more likely it is to actually identify tipping points and not only context-related fluctuations. Significant population developments, e.g., migration in or out of a region, as well as a major increase or drop in employment rate can indicate either positive or negative tipping points. Similarly, a positive tipping point may be observed as, for example, the growth of the local population, whereas a negative tipping point could be observed as a population decline, either through emigration or decreasing birth rates. In this framework, the close of a major industry (e.g., coal mine) in a region is often followed by significant layoffs, an increase in the local unemployment rate, and shrinking income levels and GDP. In contrast, a positive tipping point is indicated when a region is able to buffer or intervene after a major event (e.g., close of a coal mine) and actually remain stable or grow in regard to population size, income levels (same or higher as in comparison to the national average), employment, and GDP. Nonetheless, these indicators should be addressed with caution since these are only quantitative figures and do not provide insights into the perception of the local community, which might provide a different picture.

2) Context indicators: In addition to the impact indicators above, we propose assessing changes in the following context-specific indicators:

- Political composition of the local and regional government.
- Number of NGOs, businesses, and other local organisations.

- Local narratives and visions of majority (and potentially emerging minority).

The tipping context can indicate the capacities for change and resilience of a system.[62] In order to investigate the context of a socio-economic system, a full account of the basic demographic, educational, and infrastructural information should be captured (see impact indicators, Appendix 1). How a region is governed is another question to consider, in particular, the indicator of the political composition of local and regional governments. For instance, the voting patterns can offer insights into the level of progressiveness and local attitudes influencing local decision-making and possible interventions. In addition, we suggest paying particular attention to local narratives and visions of local actors. These can point to envisioned changes (mainstream and emerging narratives) and help to identify potential key actors, change agents, and intervention points. A detailed overview of suggested context and impact (pre- and post-tipping) indicators is provided in TABLES 8 and 9 (see Appendix A).

Tipping context and impact are influenced by interventions. Hence, both should be analysed for the following interventions:[63]

- Industry interventions: Those close to a power plant or mine.
- Policy interventions: Introduction of pollution acts or renewable energy acts.
- Government elections at different levels.
- Public information campaigns by NGOs or governments on clean air or water and climate protection.
- Key agents: Local actors – social/ institutional entrepreneurs.

Tipping interventions are deliberate actions that influence the socio-economic context of a region through initiating certain processes (NGOs, industry, and government) or mitigating others (government and NGOs).

62. Tàbara, et al., 'Positive tipping points.'

63. Table 10 provides a detailed account of intervention indicators (See Appendix A).

This non-exhaustive list of indicators provides a starting point for seeking out tipping interventions in relation to significant systemic change.

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Appendix A

TABLE 8. Quantitative Indicators for The Context Pre- and Post-Tipping in Coal- Or Carbon-Intensive Regions.

Variable type	Variable examples	Possible questions
General context		
Demographics	Population. Composition of gender. Education levels. Age. Migration patterns. Life expectancy (only relevant over a longer time frame).	Who lives in the carbon-intensive regions (demographics, gender, and minorities)? What are they doing in terms of jobs and education? What migration patterns can be observed? (If any) What are the ongoing trends?
Socio-economic trends and changes	GDP. Household income levels. Poverty rate. Employment and unemployment levels.	What are the economic, social, and human resources and capacities available to transform the region?
Business/industry context		
Importance of incumbent dominant industry (e.g., coal and steel)	Number of employees/shares of local employment. Contribution to local GDP. Subsidies/subsidies relative to turnover and value-added. Production output (e.g., MW and tonnes of coal).	Who are the incumbents and dominant industry actors? How important are they for the local economy and employment market? What is the local economic contribution and value of the incumbent industry? How many public subsidies in relation to value-added do they receive?
Presence and importance of other sectors	Number of companies employing 10%, 20%, and 25% of the workforce. Share of public vs. private sector in: • Regional GDP. • Employment.	How important are other sectors (e.g., industry, service) for the region? How many people are employed in these sectors? What is the annual contribution to GDP by these sectors? Are these sectors supported by public policy?
	• Number of employees/shares of local employment. • Contribution to local GDP.	

Variable type	Variable examples	Possible questions
Presence and importance of green sectors	Number of employees/shares of local employment. Number of companies active in the regions. Contribution to local GDP. Subsidies/subsidies relative to turnover and value-added. Skills needed for expansion.	Are new 'green' companies present? Can they step up and grow into the niche left by the carbon-intensive business? How important are they for the local economy and employment market? What is the local economic contribution and value of the green industry? How many public subsidies in relation to value-added do they receive? Can the employees from the carbon-intensive industry be shifted or retrained to meet the needs of the green industry?
Political context		
Political composition of government	EU parliament. National government. State government. Local government.	Who are the governing actors and who is in opposition? What is their position on coal (i.e., carbon-intensive industries)? What role does coal play in legitimising their power?
Public opinion at the national, regional, and local level	Acceptance of climate science. Acceptance of renewable energy deployment. Support of government. Trust in government. Civil engagement and own participation in public consultations.	What sentiments do local and regional community members convey about questions of climate change, acceptance of renewable energy, trust in government bodies, and their participation in transformation processes?
Public budgets	Funding for different levels/ministries and branches of government (total or spending per capita).	Is public investment supporting possible programmes? Does public investment support programmes that already exist? Can the region tap into them?

Variable type	Variable examples	Possible questions
	Climate protection. Energy funding/subsidies. Labour (retraining and upskilling measures). Social welfare. Research and education. Innovation. Public spending/investments relative to GDP. Local/municipal. Regional. National.	Are the public budgets balanced? Is there room for additional spending? Are existing investments or other structural change programmes available? How high is the public debt relative to GDP?
Societal context		
Civil society	Share of citizens active in local clubs (all types). Number/share of honorary posts. Number of charitable organisations.	Are citizens engaged in improving and shaping their community?
Environmental and social NGOs	Number of NGOs focusing on climate and environmental protection (e.g., anti-coal). Number of other associations and NGOs with a focus on coal (e.g., community support and advocacy).	Are citizens engaged in improving the environment in their community, region, country, or in general? What is their position on coal? What is their position and activities regarding the specific activity/industry that closed or was discontinued?
NGOs membership	Number of members (funding or active) in climate and environmental NGOs and other associates	What is the membership size of these NGOs? How many people actively engage or are they funding members? What political influence do these NGOs have?
Mining and steel/ Energy Unions	Number of members at the national, regional, and local levels.	What is the membership size of these unions at different levels? What is their position on coal?
CSR activities by local industry	Local industry funding/support for: Cultural events/activities Sport events/activities	How much funding does the local/ regional coal provide for regional cultural and sport events/activities?

Variable type	Variable examples	Possible questions
		How strong do local associations and community organisations depend on the local industry support?
Media discourse	Media coverage of coal (intensity). Number of newspaper articles. Number of public service TV (news) reports. Number of online newspaper articles or social media (e.g., Facebook and Instagram). Media coverage of coal (direction). Number of positive (pro-closing and pro-transition). and negative (anti-closing and anti-transition) newspaper articles. Number of positive/negative public service TV (news) reports.	How often does coal appear in the local news (newspapers, online news, and social media)?

Source: Prepared by authors.

TABLE 9. Qualitative Indicators for the Context Pre- and Post-Tipping in Coal- or Carbon-Intensive Regions.

Variable type	Variable examples	Possible questions
Perceptions and narratives about the present		
Frames	Frames used by actors in regard to: Coal. Local/ regional actors. Local community. Workers. Government. Industry. Civil society organisations (NGOs and unions). Media.	What are the dominant and minority frames used in election campaigns, public speeches and public events, parliament discussions, parliamentary inquiries, industry advertisements, presentations at industry events and public fairs, and political media articles and social media?

Variable type	Variable examples	Possible questions
		How do these frames legitimise/ delegitimise coal (i.e., carbon-intensive industries) as a regional economic resource? What do people associate with coal?
Self-image	Self-perception: What do people think about their place in that region and that region's place in the world? Who are 'we'?	Who are we? What do we do? What can (not) we do? What is our place in the world?
External perception	External perception: What do people outside the affected region think about it, its people, and what happens there? Who are 'they'?	Who are the people in the region? What do they do? What can (not) they do? What is their place in the world?
Perceptions about coal in the region	Narratives used by actors in regard to coal: Local/ regional actors. Local community/ workers. Government. Parliament. Industry and industry associations. Civil society organisations. NGOs. Unions. General national discourse. National media.	What is coal? Why is coal important? What problems are caused by coal? Is coal, in balance, good or bad?
Perceptions about coal beyond the region (e.g., in the capital)	Narratives used by actors in regard to coal: National actors: government and parliament. Industry and industry associations. Other industries. Civil society organisations. NGOs/Unions. General national discourse. National media.	What is coal? Why is coal important? What problems are caused by coal? Is coal, in balance, good or bad?

Variable type	Variable examples	Possible questions
Perceptions about the future		
Internal visions	Narrative visions put forth (e.g., dominant or minority) by local actors.	Who do we want to become? What do we want our region and community to develop into? What will we do in the future? What should be our place in the world?
External visions	Narrative visions put forth (e.g., dominant or minority) by national and European actors.	Who do we want the region to become? What do we want that this region or community develop into? What will they do in the future? What should be their place in the world?

Source: Prepared by authors.

TABLE 10. Intervention Indicators in Coal- or Carbon-Intensive Regions.

Intervention type	Intervention example	Intended effect
Policy interventions		
Public investments	Building new infrastructure (e.g., rail or road).	Improving transport of goods and people to/from the region; allowing longer commuting.
Investment support	Public-private partnerships.	Subsidies for private actors investing in the region to trigger investments in new economic activity; jobs creation.
	Soft loans.	Low-interest loans for regional investments to trigger new economic activity, and job creation.
Subsidies	Subsidies or tax exemptions for companies present.	Keeping companies in the region; maintaining employment.
	Subsidies or tax exemptions for companies expanding in or to the region.	Attracting further companies to the region; creating further jobs in already existing businesses.

Intervention type	Intervention example	Intended effect
Education	Funding universities and new university programmes.	Attracting young, qualified students to the region; creating the skills needed for the envisioned transition.
	Founding R&D institutes.	Attracting skilled R&D people to the region; triggering regional spin-offs.
Deliberation processes	Local engagement processes.	Building a new vision for the region.
Population management	Support for families moving away.	Reducing unemployment in affected regions; creating new opportunities for citizens and other regions.
	Lowering property tax; soft loans for buying property in regions.	Keeping population in the region by supporting house ownership.
Local interventions	Funding local initiatives and associations.	Supporting local social capital.
Business/industry interventions		
Investments	Expanding existing operations.	Expanding local value creation and new jobs.
	Found new operations	Expanding local value creation and new jobs.
	Relocating from other regions.	
Education	Re-training existing employees.	Enhancing skills and directing them towards what is needed in the future (keep existing employees hired).
	Training new employees.	Teaching new employees in necessary skills for future operations and the scope of companies.
	Working with the government to design new education programmes and university foci.	Teaching new employees necessary skills for future operations, the scope of companies, and the governmental vision for the region.
Entrepreneur initiatives	Start-ups and technology and business innovation.	Establishing a flexible and supportive business environment for start-ups and other entrepreneurial innovations.

Intervention type	Intervention example	Intended effect
Societal interventions		
Citizen initiatives	Network support for businesses and other stakeholders.	Creating a movement of orchestrated policy, business, and civil society actions to achieve a new vision for the region.
	Bottom-up visionary discussion processes.	Building a new vision for the region; building social trust and associational networks.
Education	Information campaigns about environmental awareness and health.	Raising awareness, educating, and building local social capacity.
Social networks	Collective action.	Supporting local initiatives and NGOs in order to create or maintain social capital.

Source: Prepared by authors.