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DOI
10.1007/978-3-031-50762-5_7

Publication date
2024

Document Version
Final published version

Published in
Positive Tipping Points Towards Sustainability

Citation (APA)
Mangalagiu, D., Lieu, J., Biddau, F., Lilliestam, J., Veland, S., Sarrica, M., Martinez-Reyes, A., Mey, F., & Mandel, A. (2024). Exploring Transition in Coal- and Carbon-Intensive Regions Through an Interdisciplinary Lens. In J. D. Tabara, A. Flamos, D. Mangalagiu, & S. Michas (Eds.), *Positive Tipping Points Towards Sustainability : Understanding the Conditions and Strategies for Fast Decarbonization in Regions* (pp. 127-149). (Springer Climate; Vol. Part F2470). Springer. https://doi.org/10.1007/978-3-031-50762-5_7

Exploring Transition in Coal- and Carbon-Intensive Regions Through an Interdisciplinary Lens

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Abstract This chapter introduces an interdisciplinary perspective to investigate the transition process and to identify empirical evidence of social-ecological tipping points (SETPs) in the case studies on coal and carbon intensive regions (CCIRs) analyzed in the project TIPPING+. The interdisciplinary lens considers different modes of thought, frameworks, and multiple perspectives and interests from diverse stakeholders, a systems' understanding, and different culture considerations across the CCIRs. Within this interdisciplinary process, we applied various lenses to study the potential for SETPs by combining insights from human geography, social psychology, regional socio-technical systems, and political economy perspectives on the phases of low carbon transitions and on the justice component of the transitions. Subsequently, this chapter gives an overview of how the eight CCIRs case studies in this book have applied various interdisciplinary lenses to investigate the regional transition and the emergence of SETPs.

Keywords Energy transition · Social-ecological tipping points · Coal and carbon intensive regions · Interdisciplinarity · Socio-technical transition · Socio-ecological transition

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J. D. Tàbara et al. (eds.), *Positive Tipping Points Towards Sustainability*, Springer Climate, https://doi.org/10.1007/978-3-031-50762-5_7

1 Introduction

National and international climate mitigation policies and strategies often do not consider the nuanced needs and real constraints and opportunities present at the regional level, resulting in misalignments between (inter)national climate policy goals and local conditions and priorities. The challenges are more acute in coal and carbon-intensive regions (CCIRs) that are economically dependent on fossil fuels but must also meet national and EU climate change targets.

National climate policies often lack credibility at the regional and local level as longer-term climate goals do not resonate with the immediate socio-economic needs nor actual possibilities for transformation observed in the actual local context (Amundsen et al., 2018; Frantál et al., 2022). Moreover, national policies do not account for individuals' preferences and how they respond to fast socio-structural changes occurring at local level, or they are based on assumptions which can lead to a limited understanding of the behavior and abilities to adapt or innovate at a local level (Sarrica et al., 2018). In regional socio-ecological systems, different community values, social identities and cultural practices unfold and may—or may not—be integrated as part of broader climate mitigation actions. Another issue is that, while coal and fossil fuels are well defined technological sectors, CCIRs are not clearly defined and are rarely systematically analyzed as a 'complex system' (Allen et al., 2017). There is a lack of systemic understanding of systems' dynamics regarding CCIRs. Looking at a region as a complex system involves considering multiple geographical, social, cultural, and political dimensions that are integral starting points of its analysis. Failing to systematically consider these multiple dimensions and perspectives can lead to the ineffective implementation of mitigation actions and climate policies at all governance levels (Tàbara et al., 2019; Geels et al., 2017).

In the case studies of this book, we conducted theoretical and empirical in-depth investigation in CCIRs transitioning to low-carbon futures to understand how Social-Ecological Tipping Points (SETPs) emerge. Tipping points are well understood in the natural sciences. They have been documented in ecosystems (Lovejoy & Nobre, 2018; Möllmann et al., 2021) and physical systems (Eisenman & Wettlaufer, 2009). In social systems, meanwhile, tipping points are less well understood. In TIPPING+ we used interdisciplinary social science to understand the fundamental changes in sociodemographic, geographical, psychological, cultural,

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political, and economic patterns of interaction in the socio-ecological system. To examine societal tipping points, we have examined statistical changes in these patterns, as well as the narratives that have described, catalyzed, and opposed a post-coal transition. Lieu et al. (2020) have described these narratives as on-stream, off-stream, and transformation stream. Through workshops and interviews with local community actors across the numerous case studies in Tipping+, we engaged in conversations to identify potential triggers for positive tipping points (following Tàbara et al., 2019). Our purpose has been to find patterns and narratives that have led or are leading to the emergence of SETPs, both positive and negative. For instance, the decision of 'leaving fossil fuels in the ground' could be understood as a positive outcome of a tipping intervention from a climate policy and sectorial perspective as it could trigger alternative energy innovations and technologies if they are mature enough and there is an enabling environment. However, the practical consequences of such a decision at the regional and local levels in terms of employment, cultural identity, and social-ecological restructuring need a careful examination before being qualified as 'positive' (Dale et al., 2018; Dale & Kristoffersen, 2018). Such an interdisciplinary process enabled us to have a multifaceted and nuanced view of the transitions in CCIRs.

In this chapter, we first introduce the interdisciplinary foundations of the project to investigate the transition process in the CCIR regions under study. Subsequently, we give an overview of how the eight regional case studies on which we focus in this book have used an interdisciplinary lens to investigate the regional transition and the emergence of SETPs.

2 Exploring Transitions Through an Interdisciplinary Lens

In our analysis of assessing potential SETPs, we explore different understandings of transition, transformation, or system changes. We first provide a broad overview of SETP based on socio-technical systems theories (STS) and socio-ecological systems theories (SES). We then introduce concepts from human geography, social psychology, regional socio-technical, and economic perspectives to have a broader understanding of *low-carbon transitions* and *social justice.*

The study of transitions, transition phases, transformations as well as the very notion of tipping points (TPs) are grounded in complex systems theory, which in turn builds on general systems theory (Ashby, 1957; Holland et al., 1963; von Bertalanffy, 1968). These concepts are adopted by many disciplinary theoretical perspectives such as economics, socio-technical system theories, socio-ecological systems theories, resilience perspective originating from SES (Folke, 2006) and others.

The STS theories study systemic change or transitions as a progressive shift of regimes that are spread across economic and political structures, norms and values, and patterns of behavior. These regimes influence the development of technological sectors (Geels & Schot, 2007; Wesselink et al., 2020). Rotmans et al. (2001)

advanced the thinking behind socio-technical transition, distinguishing between predevelopment, acceleration, take-off, and stabilization phases of socio-technical change. In a similar way, Gunderson and Holling (2002) advanced the thinking that an SES can shift into fundamentally different configurations after a release phase opens for reorganization and exploitation of new structures, followed by a new phase of conserving structures.

The SES theories try to explain how a system changes by considering the environment, society, and economies as fundamental parts of the system. In SES theories, transformation happens when a tipping point is reached (Wesselink et al., 2020). Building on SES, resilience scholars see the transition as a subset of a larger transformation (Herrfahrdt-Pähle et al., 2020).

Expressing elements of both SES and STS-style theories of change, the Adaptive cycle approach conceptualizes interlinked societal/technical and ecological systems change into four cyclical phases (Gunderson & Holling, 2002). As a system moves through the phases of the adaptive cycle, a system may remain resilient to processes of change at greater or smaller scales or shift into a fundamentally different configuration. A tipping point will happen following a release phase that provides potential for reorganization and exploitation of new structures, followed by a new phase of conserving structures.

Both SES and STS theories have identified general patterns of how transitions unfold over time, including types of change (incremental and abrupt), their nonlinearity (thresholds and tipping points in disruptive innovations and events), and multiple phases of transitions (Loorbach et al., 2017). The transition phases of STS, SES, and adaptive cycle perspectives have corresponding concepts and phases (Table 1).

The socio-technical perspective emphasizes the deployment and diffusion of technological innovations as the focus of change and implies a management and engineering perspective focusing on human-technology coupled systems (i.e., technology-society relationship). The STS perspective is grounded in innovation research, science and technology studies and evolutionary economics (Loorbach et al., 2017; Barile & Saviano, 2018). It has a narrower focus and has been accused to have a selective bias toward technological innovations and the transition of socio-technical systems providing goods and services to society (i.e., food, water, energy, waste).

The socio-ecological perspective, on the contrary, emphasizes the interactions between natural capital and ecosystem services and implies adopting a perspective

Table 1 Synopsis of transition phases in socio-technical, socio-ecological, and adaptive cycle approaches

Socio-technical transition phases	Socio-ecological transition phases	Adaptive cycle phases
Predevelopment	Pre-transformation	Release
Acceleration	Preparation	Reorganization
Take off	Navigation	Exploitation
Stabilization	Institutionalization	Conservation

centered on human-nature coupled systems (i.e., the environment-society relationship, Ostrom, 2009). The SES perspective is grounded in sustainability science and environmental studies focusing on environmental assessment, environmental policy, and sustainability governance and addresses sustainability transformations with a whole system perspective. Here, transformation refers to the creation of fundamentally new systems of human-environmental interactions and feedback (Walker et al., 2004), thus involving the change of multiple elements of socio-ecological systems such as beliefs, behaviors, and institutions at multiple levels (Moore et al., 2014). From this perspective, SETPs refer to a family of frameworks and concepts that describe the process of socio-ecological transformations (Totten, 2012; Westley et al., 2013; Moore et al., 2014; Tàbara et al., 2018). According to these frameworks, a socio-ecological system such as a CCIR may go through a series of events whose effects accumulate and, at some point or points in time, the SETPs, cause changes in key elements of the system (Moore et al., 2014; Tàbara et al., 2018). Such changes alter the feedback mechanisms stabilizing the system and bringing cascading effects that 'move' or attract the system toward a new trajectory and different state creating new feedback loops (see also Olsson & Moore, 2023). Put it simply, from a SES perspective, this involves the 'unmaking' and 'making' of given sets of relationships making up a system (Feola et al., 2021). While for an STS perspective it involves the destabilization-reconfiguration of a socio-technical system that is characterized by break-down and build-up dynamics or processes of 'exnovation'/phase-out and innovation/phase-in (cf. Hebinck et al., 2022).

Among SES approaches, the adaptive cycle has a cyclical understanding of change, where the transformative (tipping point) potential of each cycle is not given, but dependent on the presence of key drivers of change at greater or smaller scales. The adaptive cycle was conceptualized by Gunderson and Holling (2002) based on observations of marine ecosystems and expanded to also consider human societal and technical dimensions such as political regimes. Their observation was that all systems will exhibit a similar pattern of change: a conservation stage in which structures are maintained (a late-succession forest; the end of an elective cycle), giving way to a release phase (fire; elections) that allows for a reorganization (plant pioneers; reelection or new government) and exploitation (plant succession, policy implementation), before a new period of conservation of structures (c.f. resalliance.org for examples and literature). The equivalent of a tipping point may or may not be induced between the reorganization and exploitation phases, pushing the system out of its previous state and into a new one (Olsson et al. 2014). For instance, a forest ecosystem becoming open grassland or desert; a democratic system of governance becoming a dictatorship; a former coal region becoming a node in a larger network of renewable energy infrastructures. Pelling and Dill (2010) describe disasters as potential tipping points that change the trajectory of a social system. Inherently, disasters are events that overwhelm capacity to respond at a given scale, requiring mobilization of resources at greater scales to either stabilize or transform a vulnerable SES. For the purpose of deliberate, positive tipping points, the ability to engineer a disturbance that catalyzes reorganization and a transform into a desired SES state depends on the capacities and potential present in the dynamics of

systems at scales above and below. Gunderson and Holling (2002) captured such cross-scale aspects in the notion of a *panarchy*, conceptualized as nested dynamic systems across temporal and spatial scales.

2.1 Human Geography Perspective

Human geography builds on space, place, and scale as three foundational concepts. For CCIRs, these three allow consideration of how transformative change in an STS or SES is experienced and located in space and place, as well as how such change is scaled from personal to global levels and across time. Space is at once a material and conceptual term that is experienced by an individual or a culture and includes physical and cultural phenomena (Massey, 2005). The sense of space in many ways precludes the sense of place, setting the conditions for how a given place is experienced. For instance, a given place within a CCIR may be experienced as a site of opportunity and growth to a person whose sense of space is vested in new economic activities, while the same place may be experienced as a site of loss and ruination for a person whose sense of space is rooted in a coal mining identity.

Scale dimensions in CCIRs are an important consideration for just transition. In the pursuit of low-carbon societies, it is often the resilience of large-scale SES systems and states such as regional and national governance and ways of life that it sought, while local or individual levels are required to transform (Amundsen et al., 2018). There may be a sense of injustice among those whose lives are required to transform if their quality of life is expected to decrease to support the resilience of life of others. The experience of such tipping points may not be unlike that of a disaster (Pelling & Dill, 2010). Further, the scale dimensions in CCIRs are important in terms of how lessons on transitions can be scaled. It may be, for instance, that lessons from transitions in coal region STS/SES founded on black anthracite coal cannot be scaled up to include regions dependent on lignite since the two have fundamentally different forms of extraction and economic profitability (cf. Veland et al., 2023). Finally, the unit of geographical scale called a CCIR may not be the best unit of analysis or policy for the transformation of that same region. While coal may have unified the region historically, the features of the transformed region may align with a new or different formal, functional, or administrative region.

In the case of the CCIR represented in the four stages (Fig. 1), the region may go through periods of exploitation, conservation, release, and reorganization (Gunderson & Holling, 2002) and retain the same characteristics. For instance, the drop in coal prices can represent dynamics in a nested SES that ushers then release of a conservation-phase coal economy. This might in turn cause a reorganization of policies, actors, and financing instruments that could tip the system into a fundamentally new post-coal domain of attraction; or the CCIR may return to exploitation of coal because the triggers of transformation were insufficient to reach a tipping point.

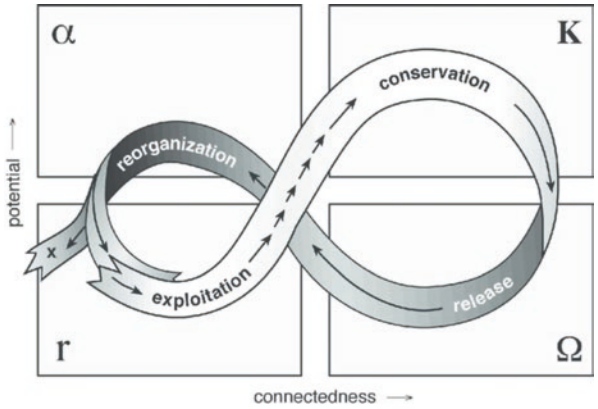

Fig. 1 The adaptive cycle (Gunderson & Holling, 2002, figure 2-1, p.34)

It is important to consider that transition phases may be conceptualized differently when approached as entangled socio-natural systems or as separated social and natural systems. The STS may have shifted fundamentally into a new way of narrating the political, technological, and economic space, and the population characteristics may have shifted to match new political and economic priorities, but the natural/ecological system, or the physical energy system infrastructure may not yet have shifted to match. The societal tipping point is in this way closely tied to the physical system limitations and opportunities.

In conceptualizing CCIRs, the most applied human geography concept of a region is the formal region (Gillespie, 2014). This concept tends to acknowledge only dominant characteristics of a region, for example, one culture, language, customs, identity, etc. (Kitchin & Thrift, 2009). In terms of governance, these formal regions are typically enclosed by administrative boundaries that are centered in urban cores. This understanding of a region does not include a justice perspective and may leave out minority groups, and work as an unconscious bias that impedes the participation of underrepresented groups. To better account for justice dimensions, a transformation may involve shifting from an existing formal coal region to one or more functional regions, their extents aligned with a diversity of economic, environmental, cultural, historical, linguistic, etc. features that are harnessed to induce positive change (or stability). Perhaps over time new administrative or functional regions would emerge.

Regarding the justice dimension in transitions in CCIRs from a STS perspective, two key themes can be identified (McCauley & Heffron, 2018). First, the just transitions idea, that communities affected negatively by the cessation of coal and other carbon-intensive industries should be somehow compensated for their losses or have access to assistance to find alternative means of economic activity. Second, the issue of justice might concern justice to future generations and to those negatively affected by coal and carbon-intensive industries today. That is, those who may have done nothing to cause climate change but are or will be suffering most from its

effects. The need to cease carbon- and coal-intensive industries is in part driven by the injustices to such populations.

2.2 Social Psychology Perspective

As discussed above, both SES and STS theories have identified general patterns of how transitions unfold over time. Both theories include—in an explicit way—references to psychological and psychosocial processes that foster or hinder change.

Social psychology has primarily engaged with STS, integrating its theories and variables (e.g., identity, values, beliefs) into socio-technical frameworks to better understand technology uptake, acceptance, and diffusion at various levels (Bögel & Upham, 2018). However, less attention has been given to how these factors contribute to regime stability or dynamics of destabilization and decline (Biddau et al., 2022b). By privileging a sectorial perspective, the discipline is not only failing to acknowledge the systemic dimension of such type of change, but also how psychosocial factors can intervene in the different phases and influence the timing and pace of transitions. This bias is particularly relevant as transitions in CCIRs involves vulnerable communities navigating a complex pathway of destabilization and reconfiguration that extends beyond a socio-technical change and encompasses struggles between the 'old' and the 'new' (Johnstone & Hielscher, 2017). The onset and success of systems' transformations depend on how actors respond to regime destabilization, and psychologically cope and adapt to the newly emerging regime (Herrfahrdt-Pähle et al., 2020).

For all these reasons, the point of intersection with psychological approaches to transition being that transformation involves the change of multiple elements of systems including beliefs, behaviors, and institutions at multiple levels (Moore et al., 2014).

In this regard, through a close comparison, it is possible to schematize some basic phases of transformations as defined by resilience scholars such as Olsson et al. (2014) and Moore et al. (2014), which relate as much to individual as to societal psychological processes of stability or transformation, and to relate different psychosocial mechanisms to the phases suggested in the literature: (1) *triggers/pre-transformation*, (2) *preparing for change*, (3) *navigating the transformation*, and (4) *institutionalizing and building the resilience of the new trajectory*.

1. The *pre-transformation* phase includes *perturbations, pressures, or crises*, which emerge internally or as exogenous forces, and which serve as an opportunity for destabilizing the dominant state. At the individual level, perturbation may be referred to as a moment in which the changes in the environment are still perceived as noise (i.e., they are not perceived as meaningful signals) (O'Brien & Klein, 2017). At the community level, problem awareness such as environmental concern or risk perception influence the preparedness for change and the identification of windows of opportunity essential for initiating transformations

(Nelson et al., 2007). At the societal level perturbations emerge in the level of agency that the different discourses acquire, and in the overall attempt made by off-stream narratives (Lieu et al., 2020) to gain space, especially on local media. Stakeholders, including social movements, can deliberately try to challenge hegemonic representations or to preserve them through, for example, the introduction of new norms or the enactment of communicative campaigns aiming at introducing new beliefs or at propagating polemic representations. Alternatively, they may react to such perturbations by conveying hegemonic discourses reproducing the dominance of certain institutions, technologies, and practices (Simoens et al., 2022).

2. The *preparation* phase, which includes all the individual and collective processes aimed at making sense of the situation and may eventually lead to envisioning alternative visions and gaining momentum around new ideas and innovations. Relevant in this phase, are all the individual processes involved in recognizing patterns of signals (e.g., schematization, naming, framing), as well as the individual and collective processes of resistance to change and of symbolic coping (e.g., social memory and place meanings), which may lead to avoidance and to suppressing the need for further elaborations of alternatives (e.g., use of heuristics, denial) and undermine the community capacity to respond to new problems and opportunities (Wilson, 2014).
3. The *navigation* phase is characterized by the selection, learning, and adoption subprocesses. In the Social Representations theory, this phase is characterized by the actual elaboration of new representation and eventually in the polyphasic presence of multiple and incoherent representations and practices. The discrepancy between perceived and observed change is a crucial element here, especially to move from a transformation in behaviors towards an actual process of learning and elaboration of significant behaviors, new social norms, meanings, and identities.
4. Finally, the *institutionalization of the new trajectory* phase is characterized by routinization, strengthening cross-scale relationships, and stabilization. At the individual level this would be noticed by the emergence of new habits. From the social representation approach, it would be identified as the establishment of new hegemonic representations. But it is probably the dynamical system approaches which could be more extensively adopted to identify this phase and especially the stabilization level, which at the societal level implies to reach a new basin of attraction and to actively maintain it. This phase covers three dimensions: (1) The institutionalization of so called "state symbologies" (i.e. the systems of symbolic meaning which are aimed at and promoting the legitimacy of a political and social structure); (2) the active management of the identity space (i.e. the ensemble of groups and identities that coexist within a society), and; (3) the implementation of "state technologies" (i.e. the material, institutional and technological means used by the state) (Leone & Sarrica, 2017; Liu et al., 2014).

Aspects of justice in transitions in CCIRs can be operationalized by using the concept of regional place identity (Paasi, 2003; Gillespie, 2014). Justice can be included

in a situated analysis within case studies to investigate the preconditions for decisive breakthroughs on the transition front, and if and which breakthroughs are taking place in practice. A just transition in practice should involve local communities and expand their agency. This can be contrasted with exclusionary and exploitative dynamics typical of extractive production systems (energy and otherwise), which are often replicated in energy transition processes (Sovacool et al., 2019). Applying a social psychology approach thus sees local-level agency and ownership, the ability of communities to participate in decision-making processes taking place at regional, national and community scales, and benefit from change as pivotal elements of a just energy transition.

2.3 Regional Socio-Technical Perspective

In the socio-technical perspective, regional transitions are considered as historically contingent processes going through different phases. Several authors have depicted these phases and described them in rather stylized patterns. There are usually three to four stages presented: (1) *initiation or emergence*, marked by experimentation and niche-innovation, (2) *early adoption and pioneering*, (3) *expansion and diffusion*, where technologies become mainstream (reconfiguration in Geels & Schot, 2007) and (4) *consolidation and stabilization*, comprising standardization processes (Chlebna & Mattes, 2020; Geels et al., 2008; Rotmans et al., 2001).

Transitions are not linear processes and may halt or progress without change being obviously visible. For example, the transition to zero-carbon energy may be progressing even if emissions are presently not decreasing, because progress is made for emerging technologies or because incumbent regime actors are being weakened. As another example, in a coal region, the closure or phase-out of the coal industry may not necessarily be aligned with and accompanied by the uptake of readily available alternative energy technologies. Instead, the predominant process may revolve around coping and managing the industry decline over an extended period and be accompanied by economic diversification, local capacity building and education measures.

In the last decade much attention has been given to phase-out, stressing its significance in creating room and momentum for innovation uptake and diffusion as well as for accelerating transitions (Rogge & Johnstone, 2017; Turnheim & Geels, 2012; Trencher et al., 2023). Recent scholarship suggests an X-curve framework that consider simultaneously the break-down or exnovation and phase-out dynamics along with build-up dynamics and innovation diffusion and phase-in (Hebinck et al., 2022) (Fig. 2).

Based on the four phases identified by the socio-technical perspective, the case study teams within the TIPPING+ project defined more specific phases to further refine the transition dynamics in a CCIR, which might differ from one CCIR to another. As an example, the case study on energy transition in Duisburg and Essen, in Germany, identified the six following phases:

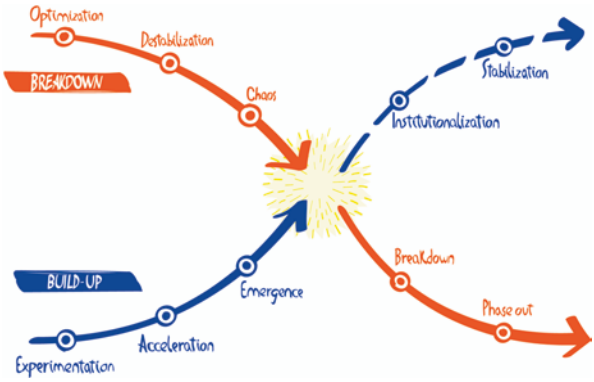

Fig. 2 The X-curve (Silvestri et al., 2022, p.5). The X refers to the specific moment when these two descending and ascending pathways interact and align

1. *Shock* triggered by the coal price crisis (tipping event);
2. *Avoiding collapse* of the system in place (e.g., interventions to stop further mine closures on basis of national energy security and social policy—coal laws);
3. *Grasping for salvation* through interventions (e.g., an introduction of coal subsidies);
4. *Denial* of looming end (e.g., the coal sector receives continuous support and only sees incremental reduction of subsidies);
5. *Loss of public legitimacy* (e.g., ultimate breakup of "coal coalition" and loss of election(s));
6. *Acceptance* (e.g., of the end of coal mining), *visioning of and pursuing new opportunities* (*possible tipping interventions).*

Regional transitions such as a coal phase-out studied in some of the case studies in TIPPING+ are embedded in multiple dynamics at local, regional, and national level. Hence, these phases may have been manifested at different times and varying intensities at different levels, and they take a long time. Our empirical case studies show that the transformation processes are still ongoing, and regions have not entered a stabilization phase yet. In addition, our empirical work suggests that it is important to terminate the old paradigm (e.g., with a "final date" and an official symbolic act) to be able to mobilize the capacities and focus on the new (e.g., visioning of new future for the region).

Regarding the aspects of justice in transitions in CCIRs, one of the main criticisms of the socio-technical perspective is that it does not address socio-ecological or distribution systems (e.g. inequality, poverty, work conditions) and issues of power, justice and plurality (Røpke, 2016; Munro, 2019). However, more recent research is bridging the socio-technical perspective and the justice aspects of regional energy transitions and distributional consequences of sustainability transitions (Jenkins et al., 2018; Sareen & Haarstad, 2018) also linking it to 'just transitions'. Such research engages with the main two frameworks for thinking on energy justice and defining it as a concept: *the three central tenets of the energy justice*

introduced by McCauley et al. (2013)—distribution, procedural and recognition justice—and applied throughout the energy system and *the eight core principles* developed by Sovacool et al. (2016): availability, affordability, due process, transparency and accountability, sustainability, intragenerational equity, intergenerational equity and responsibility.

2.4 Economics Perspective

The main processes of change in the economic realm are the structural and technological change. At the macro-economic level, structural change is measured through statistical aggregates (GDP, Investment, R&D investment, unemployment, population, GHG emissions). The process of structural change can be captured by econometric analysis that characterize the evolution of the relationship between these aggregates across regions or across time.

At the micro-economic level, structural and technological change can be captured by the evolution of production networks (i.e., input-output or buyer/seller relationships). Changes in technological paradigms induce changes in the structure of the network (Acemoglu & Azar, 2020; Gualdi & Mandel, 2019).

At the regional level, aggregate econometric results abstract away from substantial heterogeneities found at the local level and the resulting grouping of regions can be unintuitive and imperfect. The empirical work on regional cases allowed us to complement this aggregate perspective and to identify micro-level dynamics and processes that substantiate structural change at the macro level and define the following transitions phases:

1. *Awareness raising*;
2. *Emergence:* marked by experimentation, innovation in the laboratory, and demonstration in the field, to produce technologies and system architectures (Geels, 2005);
3. *Early adoption* (pre-tipping point): technologies go from the laboratory to limited commercial application;
4. *Diffusion* (at the tipping point): technologies become mainstream;
5. *Stabilization* (past the tipping point): new technologies, systems, and behaviors are both standardized and insulated from rebound effects and backsliding (Andersen & Gulbrandsen, 2020).

In the socio-economic realm, justice is strongly associated with inequality or more broadly with the distributional consequences of policies. In this context, justice can be understood firstly as a trigger, then a process and finally, an outcome. Perceived regional or social inequalities in the outcome of transition policies can have very strong impacts on social acceptance and thus be a strong barrier for implementation (e.g., the Yellow Vest movement in France). Just transition policies aim to overcome these barriers. The just transition perspective is embedded in the wider energy and environmental justice discourse emphasizing the conditions and challenges for a

fair and equitable transformation (Heffron & McCauley, 2017; LaBelle, 2017; McCauley & Heffron, 2018; Schlosberg, 2007). Simplified, 'just transition' terminology is used to synthesize environmental, labor, and social justice frames drawing on different perspectives highlighting socio-economic implications of the sustainability transformation process.

One dimension of just transition is gender, since transitions tend to affect women differently than men (Lugonzo & Chege, 2021). While research focusing on gender, social equity and intersectionality started only recently (Johnson et al., 2020; Allwood, 2020; Lahiri-Dutt, 2023), little is known about the gender impacts of CCIRs transitions. In an extensive review of literature on coal phase-outs, Walk et al. (2021) found that past coal phase-outs meant both opportunities (e.g., increased labor market participation) and challenges for women (e.g., difficulties to gain access to union structures). However, their review show that the impact of sustainability transitions on women's lives remains largely under-researched.

The design of just transition policies can be informed by data on income/wealth distribution and by models assessing the distributional consequences of policies. This shall lead to more comprehensive policy packages addressing the asymmetry of risks and opportunities across economic sectors. These shall aim at accompanying economic and geographical mobility made necessary by structural change (e.g., fostering the shift to a service economy and the concurrent increase in labor demand). Notably, addressing distributional consequences of transitions is one of the key objectives of the Just Transition Fund in the European Union.

In the discourse, justice appears in various contexts (energy justice, just transition, just energy transition, coal transition, sustainable transition). Still, the discussion about it at the policy and local level is not as vigorous as in academic studies. Moreover, the term justice probably loses its explanatory power because of the discretionary interpretation of the 'justice' and 'just transition' phrases by very different stakeholders (green NGOs, administration, trade unions). Interestingly, trade unions use the category of justice in terms of cosmopolitan justice (insecure and low-paid jobs in the Global South compared to well-paid jobs in Europe) (McCauley et al., 2019). Environmental movements use the category of restorative justice (to compensate for damages) and intergenerational and procedural justice (to engage all interested sides) (McCauley & Heffron, 2018; Page, 1999).

2.5 Summary of Transition Phases from Different Disciplinary Perspectives

After reviewing the timing and phases of transitions in CCIRs based on STS and SES theories and understanding how these phases and the justice component have been conceptualized and framed in human geography, social psychology, regional social-technical, and economic perspectives (see Table 2), we attempted to bring

Table 2 Summary of transition phases from different disciplinary perspectives

Perspectives	Transition stages	Justice components
1. Inter-disciplinary	1. Release 2. Exploitation 3. Reorganization 4. Conservation (Gunderson & Holling, 2002)	– Justice issues occur between the local, regional-, and national levels. For example, the need of changes at the local level for the stability of the national level. – Intergenerational justice, especially to those negatively affected by coal and carbon intensive industries today (Page, 1999).
2. Social psychology perspective on transitions	1. Pre-transformation 2. Preparation 3. Navigation 4. Institutionalization (Biddau et al., 2022a, 2023)	– Local-level empowerment, ownership and agency, engagement of communities in decision-making processes taking place at local regional and national scales and community's benefits from change.
3. Regional perspective on socio-technical transition	1. Initiation/emergence 2. Early adoption and pioneering 3. Expansion and diffusion 4. Consolidation and stabilization	– The three central tenets of the energy justice: distribution, procedural, and recognition justice (McCauley et al., 2013) – The eight core principles of justice: availability, affordability, due process, transparency and accountability, sustainability, intragenerational equity, intergenerational equity and responsibility (Sovacool et al., 2016).
4. Economic perspective on transitions	1.Awareness raising 2. Emergence 3. Early adoption 4. Diffusion 5. Stabilization (Mandel et al. 2022)	– Justice strongly associated with inequality and the distributional consequences of policies. – Just Transition of the workforce and the creation of decent work and quality jobs (McCauley & Heffron, 2018). – Just transition is gendered with strong focus on men in CCIRs, but transitions affect women differently than men.

together these different disciplinary perspectives to detect changes that eventually lead to SETPs.

It is important to note that the disciplinary conceptualizations of transition phases presented here encompass various facets of low-carbon transitions. While human geography and social psychology perspectives offer a broader view of transitions, the regional socio-technical and economic perspectives respectively address the phases of destabilization and decline (i.e., the phase-out) and innovation uptake and stabilization, representing the complementary processes of any transition.

Bringing in different disciplinary perspectives on understanding transitions and exploring how they consider justice can help us detect dynamics and changes that could lead to SETPs. In the following section we briefly introduce the chapters in this book section focusing on regional case studies. Each case study uses different perspectives or combines several of them and investigates potential tipping points.

Overall, the chapters underscore that the success and pace of low-carbon transitions in CCIRs are contingent on a variety of factors contributing to system stability. These encompass socio-political, socio-economic, and socio-cultural legacies, as

well as structural features ingrained in the local biophysical and infrastructural environment. Factors like economic and energy dependencies on fossil fuels, as well as the readiness of available alternatives to replace coal and carbon-intensive economies, can bolster the cultural legitimacy and dominance of the fossil fuel regime. This, in turn, constrains opportunities for alternative visions and pathways to gain space and momentum. Conversely, when the deliberate or accidental break-down of these legacies aligns with the emergence of alternatives, regions can gradually shift towards a different trajectory and configuration with the appropriate interventions.

This indicates that to gain a comprehensive understanding of the state of transition, its direction and speed, as well as actionable insights for identifying SETPs and tipping interventions, the analysis of transition dynamics must transcend isolated elements or facets and integrate both build-up and breakdown dynamics.

The theoretical and empirical perspectives presented here align with recent scholarship (Hebinck et al. 2022; Biddau et al., 2023) and suggest that deliberate destabilization and decline of existing practices and structures in CCIRs cannot occur without due consideration towards the build-up of alternatives. This includes among others developing new community identities, alternative socio-economic sectors, and viable energy futures that address justice concerns and meet community needs along the destabilization-reconfiguration pathway.

While justice elements may not be explicitly stated in each CCIR case study, justice is more broadly considered through social inclusion or exclusion and/or by exploring how different actors are positively or negatively impacted by the politics, policies, technologies, and social changes in the break-down and build-up dynamics of transition process.

3 Case Studies of Transition and Tipping Dynamics in Coal and Carbon Intensive Regions

This book compiles eight chapters that combined SES theory with other social sciences. An intersection with Human Geography is present in Dale and Sveinsdóttir (2023) and Hansen et al. (2023). A combination with Social Psychology is shown in Cots et al. (2023), Ismail et al. (2023), Apostoli Cappello (2023) and Hansen et al. (2023). Whereas a stronger Political Economy focus is given in Veland et al. (2023) and Dale and Sveinsdóttir (2023), Frankowski et al. (2023) present an Economic focus. Additionally, a Justice lens is present in Ismail et al. (2023) and Apostoli Cappello (2023) and a Regional STS approach in most chapters.

In Delatin Rodrigues and Grasso (2023) explore the social tipping processes in the transformation of the socio-energy system in the city of Civitavecchia, Italy which led to the exit from fossils fuels. The authors use the categories of destabilization and disruption as analytical tools to identify agents of transformation that can trigger social tipping processes in the Civitavecchia's 'fossil machine', conceptual category inspired by Gramsci (1929). They show how understanding the change in

the case of Civitavecchia required following the micro-socioecological aspects of destabilizing the 'naturality' of fossil energy and the practices that disrupted its reproduction and expansion. An interesting finding is how the conditions of acceptability had been constructed by what started as minority groups which gradually acquired social consistency and legitimacy to decisively oppose fossil energy. The chapter ultimately shows that the category of social tipping processes constitutes a useful framework to understanding and explaining the processes of socio-ecological change and rupture that have occurred. By emphasizing the processual dimension, it allows to identify practices that can have positive effects and understand how these effects are generated and propagated from and within a particular social-ecological environment.

In Dale and Sveinsdóttir (2023) explore the 20-year history of oil and gas extraction debate in the Lofoten archipelago in Norway to understand how a predominantly petroleum-focused economy already tipped over to alternative, low-carbon energy. By identifying important events and interventions that shaped the trajectory of the debate, the authors aim to understand how alternative visions of an oil free Lofoten emerged, took shape, and became a collectively held and performed vision of a desirable future. They argue that the success is rooted in place-based and community-driven engagement, and that a shared, communal vision of the past played an important role in creating a new, shared vision of the future. Examining the Lofoten case yields useful insights into conditions and interventions that can both unsettle the status quo of fossil fuel energy systems as well as foster lasting a transformation towards less-carbon intensive emissions trajectories.

In Cots et al. (2023) explore the role of identities and perceptions of the future in a post-coal mining region in the case of Andorra. The chapter investigates the demolition of the cooling towers of the coal power in Andorra as a definitive sign of the socio-economic transformation towards sustainable development pathways. The authors analyze the role of identities and perceptions as either enablers or barriers towards a tipping point and show how the tipping events such as the demolition of the plant are the result of decades of socio-economic, political, and cultural and ecological forces interacting which collectively move away from authoritarian identity built around coal mining. They also show how multiple socio-economic, political, cultural, and ecological forces converge and interact in incremental modes to push the original system towards a different configuration. The authors conclude that while it is reasonable to believe that the conditions for positive tipping points can be enabled through deliberate actions and policies, there is a need that normative justice safeguards, precautionary policy criteria and institutional arrangements to be already put in place in an anticipatory way so to realize positive outcomes and avoid negative ones.

In Ismail et al. (2023) explore the narrative-network dynamics in tipping processes towards low-carbon energy futures in the case of Indonesia. The chapter investigates the significance of the relationships between narratives and social networks adopting proactive measures and perspectives which contribute to the emergence of enabling conditions for tipping points leading toward sustainability. The authors utilize several established empirical studies and analysis techniques to

empirically show that the deliberate acceleration of socio-ecological systems towards tipping points that favor sustainability require the transformation of narratives propagated by agents occupying significant political and economic authority while also highlighting the importance of social network dynamics to create new, transformation-oriented narratives.

In Apostoli Cappello (2023) explores the energy transformation in Carloforte, in the island of San Pietro, Italy. By conducting an ethnographic analysis of this region—considered an exemplary case for sustainable transition—the author aims to better understand the sociocultural and community preconditions that could contribute to determining the engagement of local communities in rapid policy-driven energy transition processes, and to explore alternative routes for such developments considering the justice dimensions and the transformation processes already under way. A particular emphasis is put on understanding the agency that communities hold in rapid energy transitions. The empirical evidence gathered ethnographically shows a complex picture, suggesting the possibility of the region being on the cusp of a yet unexpressed tipping point. However, the lack of coupling of technological change with cultural transformation impedes reaching a tipping point. The author shows how the narrative construction of collective identities and an almost mythical reconstruction of the past, serving as the main local ideology, contributes to the continuation of the status quo. Moreover, she shows that any attempt at transformation driven by policy needs to be aligned with the visions and horizons of the local communities, which would not adhere to the timescales, worldviews and technologies narratives arriving from outside the communities.

In Veland et al. (2023) explore the tipping dynamics which took place in the phaseout of coal in Svalbard, Norway. By combining different disciplinary perspectives, this chapter examines the processes that led to the decision to end coal mining and how these changes affect the local economy, society, and demographic trends as well as their geopolitical implications. The authors analyze how the decision to cease coal mining, which was not only Svalbard's main industrial activity, but also crystalized in the region's identity, has been driven by economic factors such as low demand and low prices as well as by ageing infrastructure. They analyze the narratives concerning demographic and socio-economic developments in Svalbard and identify the politico-economic, demographic, and socio-cultural tipping points in this context. The chapter contributes to the understanding of transitions towards low-carbon societies, by highlighting the combined importance of societal and earth system components and identifying key enablers and barriers for positive tipping points towards more sustainable social-ecological systems.

In Hansen et al. (2023) show how relatively small decisions such as those taken by small communities and constituencies in Greenland can have major positive effects in preventing catastrophic tipping points at the global level. The Inuit Ataqatigiit-led government decision to halt all the vast oil reserves exploration in Greenland, however, is not exempt of contradictions. Many ethical and pragmatic paradoxes emerge when the transformations required towards low-carbon energy development in the EU and elsewhere are also dependent on the extraction of alternative materials and minerals affecting the very local communities that prevented a

global carbon-intensive development pathway in the first place. To overcome such paradoxes, the authors argue that it is of paramount importance to develop robust institutional mechanisms able to integrate and reconcile local worldviews and principles of justice in natural resource use -such as those that understand land cannot be privately owned across generations- with Earth system justice aimed at avoiding transgressing planetary boundaries in a fair way.

In Frankowski et al. (2023) explore the potential role of carbon taxation as a tipping intervention towards accelerated decarbonization and comparatively assess the macroeconomic effects of carbon taxation implementation in two high carbon regions undergoing coal phase-out, Upper Silesia, in Poland and Megalopolis, in Greece. To assess the macroeconomic effects of implementing a carbon tax, the authors use the MEMO model, which combines input-output with general equilibrium modelling. While the two regions considered have significant differences in their coal phase-out horizons and economies, the authors show that a carbon tax could indeed be a tipping event provided that funding and appropriate compensatory mechanisms are placed to address critical socio-economic regional needs. However, they also show that the debate about economic interventions in coal regions should be broader than providing information about existing compensation schemes, such as the Just Transition Fund or the Social Climate Fund. Buy-in from the local communities to long-term regional policy vision and nationwide policies at the intersection of social and environmental is needed in order to be able to implement ambitious climate goals and targets, which could eventually lead to a positive tipping point in the region's development trajectory.

4 Conclusions

This chapter contributes to the systemic understanding of systems' dynamics regarding CCIRs. We have introduced an interdisciplinary lens to investigate the transition process and provide empirical evidence of SETPs in eight CCIR regions. Looking at regions as complex systems and considering multiple geographical, social, cultural, and political dimensions that are integral starting points of analysis can alleviate the ineffective implementation of mitigation actions and climate policies at the regional level.

By providing concrete examples of cases and innovative methods aimed at identifying and characterizing tipping points at the regional level using an interdisciplinary social science approach, we have shown how to potentially identify tipping points, and particularly, with regard to policy action, as those moments in which due to previous cumulative and targeted interventions, a relatively small additional action or event is able to generate structural deliberate change and create different qualitative configuration aligned with sustainability.

The empirical evidence in the case studies reveals that there was no systematic evidence of SETPs in the CCIRs studied, a result which supports existing studies that claim that there is currently no documented empirical evidence of SETPs

(Milkoreit et al., 2018). However, our case studies' data lead to interesting findings, particularly regarding justice as an important part of the processes of change. We also find that incremental and/or radical changes can happen at smaller scales in social systems which then can impact socio-ecological systems over different periods of times where multiple triggering factors and actors can influence and reinforce these socio-ecological changes. The cumulative effects of changes at smaller scales of social and/or ecological changes potentially lead to transformations at a regional or wider scale.

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