Transformative Emergence: Research Challenges for Enabling Social-ecological Tipping Points Toward Regional Sustainability Transformations

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Abstract A crucial task to accelerate global decarbonisation is to understand how to enable fast, equitable, low-carbon transformations in Coal and Carbon Intensive Regions (CCIRs). In this early literature review we underlined the relevance of the boundary concept of social-ecological tipping points (SETPs) and showed that the research and policy usage of SETPs applied to accelerate structural regional sustainability transformations faces three key challenges: (I) integrating theoretical and empirical contributions from diverse social and ecological sciences, together with complexity theory (II) designing open transdisciplinary assessment processes able to represent multiple qualities of systemic change and enable regionally situated transformative capacities, and (III) moving away from one-directional metaphors of social change, or static or homogeneous conceptions of individual agency and single equilibrium in energy transitions; and instead, focus on understanding the conditions and capacities for the emergence of systemic transformations and regenerative processes across multiple levels and forms of agency. We refer to these complex and place-situated processes as learning to enable regional transformative emergence.

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1 Introduction

Accelerating global decarbonisation requires fast social learning on how to enact rapid, equitable, transformative change towards sustainability in those regions of the world most intensive in the fossil fuel production and use. However, an operational integrated theoretical corpus on how to accelerate systemic change through strategic actions toward this end is missing. For this reason, in the TIPPING+ project we underlined the relevance of the boundary concept of tipping points as a way to improve our understanding on how to approach the complexity of rapid sustainability transformations at the regional level. Tipping points and their related terms, such as leverage points, turning points, or regime shifts adopt many diverse meanings and uses in the literature (Winkelmann et al., 2022; Biggs et al., 2018; Otto et al., 2020; Farmer et al., 2019; van Ginkel et al., 2020; Shrivastava et al., 2020; Leventon et al., 2021; Fischer & Riechers, 2019; Tàbara et al., 2018; Werners et al., 2013) and this in practice shows a high polysemy and ambiguity. Based on a

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synthesis from various social sciences contributions carried out by the TIPPING+ project (Sarrica, 2020; Frantál, 2020; Mey & Lilliestam, 2020; Martínez Reyes et al., 2020; Steininger, 2020), we introduced the notion of 'social-ecological tipping points' (SETPs) and underlined three key challenges that face its robust conceptualisation, empirical operationalisation and policy use to assess and accelerate low-carbon regional sustainability transformations: first, acknowledging and integrating contributions from diverse social sciences; second, design open and transdisciplinary processes able to represent multiple qualities of systemic change; and third, support processes for the emergence of transformative place-based situated capacities at regional level. In this regard, 'positive' tipping points, as a basic, bottom-line, minimum definition was originally understood in our regional contexts as those moments of structural change derived from additional strategic but cumulative interventions that decisively contribute to create the conditions for the realisation of sustainable development goals. Whilst tipping points cannot be fully predicted when or whether they will happen, we assumed that the transformative capacities and conditions for their emergence could deliberately be enabled. Tipping points could can then be conceived as those moment in which multiple transformations may emerge across multiple levels of agency—from individual, organisational and systems levels-generating multiple learning processes and virtuous circles of regenerative feedbacks between social and biophysical systems.

2 Social-ecological Tipping Points Towards Sustainability

Traditionally, the notion of tipping points was used in environmental sciences in a negative sense, e.g., to refer to catastrophic futures or show the effects of overshooting planetary boundaries (Folke et al., 2021). However, the concept is being reframed to address the potential of positive ones and in particular to identify social actions which at one point have attained or could attain deliberate visions such as those related to sustainability or climate resilience (Sharpe & Lenton, 2021; Lenton, 2020; Tàbara et al., 2018). In the TIPPING+ project we originally defined SETPs as those hybrid thresholds derived from intertwined social and biophysical forces in which a relatively small action pushes a given social-ecological system towards an alternative development trajectory or basin of attraction. In the case of *positive* SETPs in terms of regional sustainability, such moments would occur when due to previous deliberate actions or interventions, tangible gains in terms of Sustainable Development Goals (SDGs), improvements in justice—e.g., distributive, recognition and procedural—, as well as in endogenous transformative capacities or better adapted social-ecological interactions and institutions, would be created.

SETPs may constitute an abrupt departure from an original social-ecological systems' dynamics or the creation of a completely different kind of system's configuration. Because of their inseparable nature of coupled social and biophysical interactions, SETPs lead to multiple transformations, feedbacks and qualitative changes both in economic, policy and social practices as well as in life-support

systems (Tàbara et al., 2021; Tàbara, 2023). Such transformative processes comprise of three main kinds of elements: (1) *an original context or system of reference*, the dynamics of which are driven both by social and biophysical components (2) a *tipping event or disruptive process* which may be brought about by a deliberate intervention or exogenous force, and (3) a set of *impact*s, ultimately changing *fundamentally* the original context conditions. Such consequences may be limited to one single system of reference or extend into a cascade of qualitative reactions in other systems. Conceptually, it is useful to distinguish between *sectorial tipping points*, those that occur in specific sectors or domains—as in the case of turning private mobility from fossil fuels to electric sources but without much broader institutional or cultural changes; and those *systemic tipping points* which affect a whole array of interconnected systems, and do so across a whole sort of personal, organisational and political arrangements and value-systems. The former are often referred to as transitions tipping points whereby system's end-points, policy targets, or the new system equilibria are assumed to exist, can be decided or are known beforehand (e.g., 'achieving a carbon-neutral Europe by 2050'). In contrast, in systemic tipping points such final outcomes, policy goals or new system states cannot fully be known beforehand or specified—hence no equilibrium or final system configuration is assumed (see Stirling, 2015); the latter is the case of constantly evolving social systems addressing justice claims in which no equilibria is to be expected. However, note that in regional research and policy both approaches may be complementary. Eventually, enabling the emergence of a systemic tipping point may only be possible by creating the enabling conditions for multiple sectorial tipping points in a way that then can be combined across many kinds of systems, also referred as deep transitions (Schot & Kangera, 2018). For instance, in some regions the former dependence on carbon-intense activities in the energy sector at one point in time was abandoned or 'released' in a way that the system moved towards a new basin of attraction and reorganized itself around new governance, economic, energy, and socio-cultural foundations (Coenen et al., 2018; Cowell, 2020; Crowther et al., 2021; Gailing et al., 2020).

Although it is hard to know when or whether a tipping point will happen, it is also true that when they happen, as it would be in the case of achieving climate neutrality, they rarely occur by chance. This means that in the case of social-ecological systems, the conditions for their emergence can be—at least partially—described and then possibly influenced by conscious and intentional actions. In this vein, we define tipping interventions as those deliberate actions aimed at building the necessary transformative conditions and capacities for positive transformations to happen at multiple levels of agency in a dynamic way—that is, not only regarding the large system conditions, but also with regard the individuals within that system —, thus yielding desired structural effects in a given system of reference.

3 SETPs in Regional Sustainability Transformations Research. Three Challenges Ahead

3.1 Challenge I: Acknowledging and Integrating Diverse Contributions from Social Sciences

Tipping points can be observed in individual life trajectories as well as in community arrangements and behaviours, but also in economic and distributional structures; in political, governance and institutional arrangements; in geographical and population dynamics (as those which could be derived from climatic risks, Owen & Wesselbaum, 2020; McLeman, 2017); but also in worldviews and beliefs systems, including conventions and public opinion trends (Galam & Cheon, 2020). Hence acknowledging the diverse interpretations of the notion and usages of tipping points by various social science disciplines is a first step for a robust conceptualisation and use in sustainability transformations research and action.

In psychology, models and theories of cognitive, socio-ecological and systemic processes are key to understanding qualitative change involved in socio-ecological tipping points at individual or community levels. Recent studies in human information processing investigate tipping points as 'the point at which people begin to perceive noise as signal' (O'Brien & Klein, 2017), and show asymmetries between individual expectations and the actual moment at which this point is reached (O'Brien, 2020). Going beyond the individual level of analysis, further insights on radical system transformation can be found in socio-ecological psychology, dynamical system approach, and models of change based on critical junctures theory (Liu & Pratto, 2018; Reed & Vallacher, 2020; Uskul & Oishi, 2020). Rooted in general system theory and in cultural and societal psychology, these models stress that interrelationships among elements, sub-systems and systems determine the forms of adaptation to internal and/or external factors. However, and despite the centrality of models of change, psychological studies barely refer to tipping points in energy transition (Otto et al., 2020). Thus, research could fruitfully mobilize insights from other social science fields to better understand psychological tipping points and support the emergence of sustainable development pathways. Individual, social and cultural psychological models of change should be integrated with studies on decarbonization, which use tipping point as an interpretative tool (Schmitz, 2017), for decision making (Cuppen et al., 2015), as a threshold (Strauch, 2020; Weng et al., 2018), or associated with speed and scale in non-linear transformations (Messner, 2015).

In economics, the emphasis lies on the identification, modelling and quantification of possible economic interventions such as investments in disruptive technologies (Berger et al., 2020; Lawrence, 2020; Jaakkola & van der Ploeg, 2019; Bretschger & Schaefer, 2017) and their effects in terms of structural changes in the composition of employment or GDP, competitiveness or in financial assets (Oei et al., 2020; Berger et al., 2020; Bovari et al., 2020; Semieniuk et al., 2020; Tàbara et al., 2018). A main contrast exists between those analyses being made with single equilibrium

models (Nordhaus, 2019; Lemoine & Traeger, 2016) seeking an optimal policy response and those models that account for the existence of multiple equilibria (Lamperti et al., 2018). The latter represent the move towards integrating system dynamics and agent-based approaches in future research on the economic determinants of tipping points (Hafner et al., 2020). For instance, an economic tipping point may be quantified or even partly anticipated when the costs of a technology decrease to a level which is able to replace an old one and create the conditions for the energy system to jump into a new enduring state or development dynamics (see also Patt & Lilliestam, 2018). However, many other social, cultural or political factors may contribute to adopting such new trajectory besides costs, as it is the case with electric mobility (Strauch, 2020). In this regard, several econometric methods are capable to detect structural change at macro and regional levels (Berger et al., 2020).

In policy science and governance research, an obvious focus lies on fundamental changes in power dynamics and redistribution, the role of social mobilisation or particular events inducing radical modifications in institutional arrangements bringing about new constitutional regimes or breaking down former ones (Schmitz, 2017; Linnér & Wibeck, 2021). This is the case, for instance, with those new regimes which emerged out of the fall of the Berlin wall, or more recently the attempts to change of the Chilean constitution following the uprising triggered by a relatively small increase in public transport fees (Heiss, 2021; Arias-Loyola, 2021), the failure of such structural reform may be explained due to the lack of previous necessary enabling conditions for transformative change. This line of enquiry also addresses how governance and innovation networks develop within and across time and space to the point that unfold new institutions or forms of durable collaboration or transformative agency (Galaz et al., 2016; Westley & McGowan, 2017). Tipping processes modify the degrees of freedom and the opportunity space for system transformation (Herrfahrdt-Pähle et al., 2020; Folke et al., 2021). That is, either reducing or expanding it. The latter case is when some institutional constraints are removed, or new access to resources, networks or knowledge systems are created and facilitate new forms of innovation and agents' interaction (Amundsen et al., 2018; Füg & Ibert, 2020; Jaakkola & van der Ploeg, 2019; Lutz et al., 2017; Oei et al., 2020; Wiseman, 2018; Schaffrin & Fohr, 2017). In this guise the notion of transformative governance is of special relevance to map out and identify the different kinds of capacities which may lead to tipping points towards sustainability (Hölscher & Frantzeskaki, 2020).

In inter and transdisciplinary approaches, the insights from social-ecological systems (SES) and resilience research (Folke et al., 2021; Hahn & Nykvist, 2017; Lauerburg et al., 2020) on social and natural systems are combined to understand how they mutually influence or change together. These approaches are usually conceptualized with notions such as the adaptive cycle (Walker et al., 2020) whereby successively repeated periods of stability/conservation, release, reorganization, and exploitation make up the 'panarchy' process. There may be tipping points in between each phase, but critical thresholds certainly occur in the release phase, whenever the system loses key societal or environmental components or processes that would otherwise allow reorganization to its original form. Moreover,

sustainability transformations research is developing new interpretative lens and metaphors derived from social quantum theory (O'Brien, 2016, 2018, 2021) that can be also related to ideas of tipping points. Following these perspectives, it could be argued that a tipping point would occur when a new consciousness about alternative plausible worlds, qualitative kinds of relationships and realities across personal, political and practical configurations and of the role of individual agency in turning them actionable and meaningful emerge. In this vein, sustainability transformations call for problematising current value systems and worldviews (Berzonsky & Moser, 2017) so profound changes in worldviews can also be interpreted through the perspective of deep leverage points (Davelaar, 2021). Systemic tipping points in culture, education and policy processes are largely dependent on the role played by human information and knowledge systems (HIKS; Tàbara & Chabay, 2013; van der Leeuw & Folke, 2021) and normative values (Horcea-Milcu et al., 2019; Jacobson et al., 2020); and as argued by Nyborg et al. (2016), tipping points can also be understood as the moments in which vicious circles in collective behaviour turn into positive ones, e.g., by a change of social norms and perceptions, which in turn can be induced by deliberate policies or the role of minority groups reaching a critical mass (Centola et al., 2018). Justice in particular is also considered a key driver for sustainability transformations and a crucial component to understand radical shifts in power dynamics regarding gender, ethnicity youth inclusion or the social recognition of disadvantaged groups (Allen et al., 2019; Blythe et al., 2018; Ziervogel et al., 2017) and it is also of especial significance in energy transitions research (Cronin et al., 2021; Doyon, 2019; Patterson et al., 2018; Bouzarovski & Simcock, 2017). And in this regard, justice is both a driver and an outcome of positive tipping points.

3.2 Challenge II: Designing Open Transdisciplinary Assessment Processes Able to Represent Multiple Qualities of Systemic Change and Enable Regionally Situated Transformative Capacities

When considering deep structural change, different disciplines often portray and refer to very different kinds of systems and of how their dynamic components operate. Even within those disciplines using a 'systemic approach' to sustainability transformations (Scoones et al., 2020; Fazey et al., 2017) one can find important contrasts, as it is the case with transition theory (Köhler et al., 2019), resilience and social-ecological systems research (Folke et al., 2021; Moore et al., 2014), coupled natural-human systems (CNHS; Liu et al., 2021) or organisational science (Hestad et al., 2021; Westley et al., 2011) where the use of terms as 'ecosystems' can have little to do with what natural scientists refer to. This means that they also tend to emphasize different temporal and spatial scales or conceive the role of social agency in them in different modes.

In addition, the position of the researcher with respect to the systems of reference is not independent of their analyses. Systems are always defined in relational ways and are inevitably influenced by previous socially-constructed conceptual categories. Moreover, systems operate under different logics, agents and complex dynamics (Hestad et al., 2020). Using an open, pluralistic, transdisciplinary approach it is necessary to help to overcome such limitations. However, the difficulties for providing a transdisciplinary methodology for the research of tipping points in sustainability science derives, among other reasons, from the existence of different ontologies as well as for conflicts in epistemologies and normative criteria used to describe and assess the systems of interest in which different disciplines operate (Tàbara et al., 2021; Milkoreit et al., 2018).

A key task then is how to design open, plural and transdisciplinary assessment processes for the assessment of SETPs, given that complex systems can only be described partially by one single perspective. This in turn would entail: (a) identifying and assessing different qualities of deep structural change occurring in the different kinds of systems in which transformations are needed, even though they may not necessarily or immediately appear to be connected, and (b) to represent complex dynamics derived from alternative interventions according to multiple time, spatial and social scales or dimensions. In particular, and regarding time scales, the causality of events and the apparently trivial fact that 'timing matters' are crucial elements for investigation of tipping processes in regional transformations processes: 'what happens when' - the sequence of events - is important, since actions from the distant past can initiate particular chains of reactions that have effects in the present - some largely unexpected. As Pierson (2000) suggested, 'small' events early on may have a big impact, while 'large' events at later stages may be less consequential. And in this sense, tipping points can be understood as the breaking of previous path-dependencies and lock-in situations that mark the entry to new locked-in states. However, using the chronologies, methods and time, spatial or social conceptual boundaries from one single discipline limits our ability to fully understand the complexity of addressing the full complexity of SETPs processes. To understand these complex processes, a systematic exploration of the underlying conditions and how they are conceived by different perspectives—e.g., in terms of transformability, resilience and specially, regarding systems' sensibility to possible tipping interventions—subject to multiple time lags including social hysteresis—is necessary.

3.3 Challenge III: Enabling Transformative Emergence in Coal and Carbon-Intensive Regions

Sustainability transformations, whilst occurring at multiple levels of agency, they eventually materialise in places (Salomaa & Juhola, 2020). In fact, it can be argued that sustainability science is always a situated science. Research on the transformations of energy systems needs to pay especial attention to particular places, human geographies, spatial configurations and dynamics of networks within which deep

transitions are embedded (Köhler et al., 2019; Bridge & Gailing, 2020; Coenen et al., 2021; Mattes et al., 2015; Naumann & Rudolph, 2020; Hansen & Coenen, 2015). Changing the configuration of energy production systems towards a distributed generation system based on renewables and multi-scale geographical shifts in energy demand underlines the importance of situating possible tipping points in socio-energy systems in specific places (Bridge, 2018). However, when trying to apply the concept of SETPs to sustainability transformations in places, the actual meaning of regions and communities also needs to be reconceptualised and novel modes of analysis of trans-local and trans-regional action are required. In terms of tipping points, cross-scale interactions may be better assessed and mapped out by examining the extent to which positive synergies between different kinds of actors and networks around transformative solutions are being formed, rather than using other more rigid and less action-oriented operationalisation criteria. Thus, collective action in regional contexts is very much dependent on many intertwined and complex factors which cannot easily or simply be reduced to 'bottom-up/top-down dynamics' nor to the simple aggregation of fixed individual patterns of behaviour within larger systems configurations (Byrne & Callaghan, 2014). Sustainability transformation processes do not occur only as a result of vertical and one-directional phenomena but in a much more complex, overlapping and dynamic processes of collaboration and competition between changing agents who operate under different perspectives, personal roles, interests, organisational logics or capacity of influence.

A novel approach in this regard would require a further elaboration on the notion of regions so as to integrate new components necessary to understand and enable sustainability transformations. That is, to consider not only the *formal regions* based on the 'sameness' in geographic, administrative, cultural or economic attributes; or the *functional regions* defined in terms of their operational links, flows and interactions; or *the perceptual or cultural region* related to areas socially constructed by cultural beliefs, feelings or attachment, or other collective imaginaries. This new approach may entail extending the functional category of region based on identifying what would be needed to be transformed for achieving a positive tipping point in sustainability terms. This would be close to what the EU refered to the Accelerator Regions (Hedegaard et al., 2020), although a *transformative region*, would also encompass dynamic transformations at multiple levels of agency, as well as in the other formal and cultural defining categories.

However, considering such a novel approach to regional change would also need to move away from simple and one-directional metaphors of causality in socio-cultural and technological change (see Hughes et al., 2022) towards understanding and enabling the conditions for *transformative emergence*. Using the notion of transformative emergence in tipping points would mean to abandon fixed and static ideas of individual agency (e.g., the rational actor paradigm) in their interactions with other organisational or large systems' levels. That is, moving from synchronic perspectives of systems' reconfigurations and changes occurring only at one point in time or one single level—e.g., at individual and organisational level with direct dependency among them—to understanding what multiple transformations of

properties may emerge and influence in a recursive way multiple configurations at multiple periods of time—and also to acknowledge that no single or direct dependency relationships between agents and systems may occur among them (van Dijk, 2020; Humphreys, 2020; Schot & Kangera, 2018; Guay & Sartenaer, 2016). Further research using such dynamic understanding of agency-systems interactions in which both agents and systems do and need to change at the same time, may have profound implications for sustainability science and policy. And in particular for those approaches, such as in modelling, aimed at identifying positive tipping points derived from coupling multiple systems of solutions at different scales or domains of action.

In short, instead of one-directional and single end-point approaches, we advocate for a better understanding of those kinds of tipping interventions which may help to create the conditions for the emergence of more lasting and profound systemic effects in diverse but coupled social-ecological systems of reference; and do so at different levels of agency with special attention to be placed to individuals, communities and regions with higher potential for fast, positive systemic impact. Transforming systems require empowered transformative agency operating in enabling environments which induce to such transformations in a recursive, 'multichronic' mode. This novel approach to accelerating transformative actions in regions and communities would also call for the integration of both human and biophysical forces of change, insofar that improvements in biophysical conditions translate into improvements in human quality of life conditions and in turn generate multiple positive retroactive feedbacks in many kinds of systems (for the case of food systems see (Pereira et al., 2020)). But in any case, the possibility of such self-reinforcing positive learning loops leading to a systemic positive tipping point would be conditioned by the agents, networks and capacities required to implement transformative visions, and strategies in each particular regional contexts of action (Tàbara et al., 2018).

4 Conclusion

The need for understanding how to accelerate systemic and qualitative change towards sustainability derived from relative strategic and sensitive interventions is opening a large corpus of research on social-ecological tipping points. One additional reason for the attractiveness of this concept in sustainability science may lie in the belief—or hope—that few relatively small actions or marginal additional forces can eventually lead to large, desirable and profound system' changes, as when seemingly trivial or imperceivable events trigger irreversible and accelerating chains of reactions (Nuttall, 2012). However, in the case of deliberate sustainability transformations, such belief has not yet been fully proven to be true in empirical or at large-scale terms. Or at least, such belief will only be confirmed when we better understand the previous and complex conditions and deliberate interventions that made such large systems' change possible in the first place. Whilst it may be the

case that a disruptive event, intentional policy action, individual behaviour or technology may precipitate rapid change in a given system, whether it will eventually contribute to wider sustainability will depend very much on the extent to which many other conditions, contextual factors, previous forces of change come into play.

The EU funded TIPPING+ project was an attempt to dealt mostly with Challenge I, insofar that it aimed to explore in an open way how different social science disciplines, and in particular human geography, anthropology, social psychology, economics and sustainability policy analysis understood the complex notion of tipping points and then how these could be used to understand regional decarbonisations processes. From this plural approach, it also aimed to provide empirical insights on fast structural change which could be also relevant to inform public policies. The COVID pandemic affected about two thirds of duration of the project which meant that many interactions with stakeholders and other potential methodological innovations regarding Challenge II could not be carried out. Under these conditions, a particular emphasis was placed on developing theoretical perspectives that could help the potential for transformations in coal and carbon intensive regions, such as the Just Social-Ecological Tipping Scales (Mangalagiu et al., 2023) or more generally, using non-linear, complex social-ecological systems approaches, also the conditions to move towards regenerative development pathways (Tàbara, 2023).

Current research on tipping points is carried out at a very theoretical or still using stylised modelling approaches that are hard to be applied to inform and support real-life social and political processes of deliberate sustainability transformations. The TIPPING+ project found out that definitions and understandings on tipping points vary considerably among different disciplines, which also makes it difficult a cross-disciplinary understanding of the kinds of systems, structural changes or effects of the different tipping phenomena that they refer to. In the future, further human interfacing capacities and transdisciplinary research spaces will be needed able to address such complex boundary concepts in a way that can engage, facilitate dialogue and support second-order learning (doing things different under a different cognitive and normative paradigm or vision) among relevant actors in the present conditions of accelerated environmental change.

Tipping points, conceptualised as discontinuities in a development trajectory, as thresholds of qualitative structural change or as a move toward new basins of attraction, occur in many different kinds of systems, relationships and levels of agency; so, they can hardly be circumscribed to one single system of reference. However, positive tipping points, when they happen they rarely occur by chance. The building conditions by which SEPTs eventually unfold can be systematically described and analysed, albeit always partially and limited to the perspectives and tools that researchers use in their descriptions. But for this knowledge to become a solid basis for action, our review underlined three key challenges for research. First, acknowledging and connecting the contributions from diverse social sciences with complexity theory (Byrne & Callaghan, 2014), also using a situated, place-based approach. Second, designing open transdisciplinary assessment processes able to assess multiple understandings of qualitative change in social-ecological systems, with special attention paid to supporting transformative capacities; and third, rethinking the

nature and interactions between agents and systems from a transformative emergence perspective in which multiple transformations and learning feedbacks can emerge—in a 'multi-synchronic' way over multiple periods of time and across different levels and forms of social-ecological agency.

A better understanding of the social, economic and environmental challenges that individuals and groups encounter before, during, and after a given regional systemic transformation might also help clarify to whom the tipping points may impact positively or negatively, e.g., in terms of justice and sustainability. Some of these challenges or injustices might originate from power asymmetries already in the system, such as social discrimination preventing participation in decision making spaces and gender inequities (Clancy et al., 2020; Johnson et al., 2020). Therefore, once both a target or directly affected group(s) and non-target ones have been identified, the sustainability potential of tipping interventions may be better tailored accordingly.

In this contribution we argued that one of the most urgent tasks to move human societies towards sustainability has to do with learning how to accelerate sustainability change in those areas most intensive in the extraction and use of fossil fuels. Sustainability transformations research needs then to pay special attention to understanding the conditions by which coal and carbon intensive regions have managed to move to alternative, better-off structural situations and/or how radically clean-energy and socially just trajectories could be taken in other regions. However, and although the exact moment in which positive tipping points may occur cannot be known beforehand, we have argued that it is possible for sustainability and interdisciplinary social-environmental sciences to contribute meaningfully to identifying and assessing the societal and policy learning processes to build the transformative conditions and capacities for their emergence.

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