

Enabling positive tipping points towards clean-energy transitions in coal- and carbon-intensive Regions

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Deliverable 3.1:
Policy and governance perspective on tipping points - A literature review and analytical framework

Work Package: 3

Leader Organization: Institute for Advanced Sustainability Studies e.V. (IASS)

Authors: Franziska Mey (IASS), Johan Lilliestam (IASS)

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Preface

TIPPING+ will provide an empirical in-depth social science understanding of fundamental changes in sociodemographic, geographical, psychological, cultural, political, and economic patterns which give rise to Social-Ecological Tipping Points, both positive and negative in relation to socio-energy regional systems. Such empirical and theoretical insights will shed new light on the interdependencies between changes in regional socio-cultural structures and the technological, regulatory and investment-related requirements for embracing (or failing to embrace) low-carbon, clean-energy and competitive development pathways in selected coal- and carbon-intensive case study regions. The overall goal is to understand why and under which conditions, a given social-ecological regional system heavily dependent on coal and carbon-intensive activities may flip into a low-carbon, clean energy development trajectory – or on the contrary may fall into an opposite trajectory with all its negative implications. Towards this goal, main focus of TIPPING+ is the participatory co-production of knowledge on the driving forces and deliberate tipping interventions leading to the emergence of positive tipping points toward clean energy transitions in European coal- and carbon-intensive regions.

Who We Are

	Participant Name	Short Name	Country	Logo
1	Global Climate Forum e.V.	GCF	DE	
2	Delft University of Technology	TUD	NL	
3	CIRPA - Università Degli Studi di Roma La Sapienza	UR	IT	
4	Institute for Advanced Sustainability Studies e.V.	IASS	DE	
5	Paris School of Economics	EEP PSE	FR	
6	Nordland Research Institute	NRI	NO	
7	Universitaet Graz	UG	AT	
8	University of Piraeus Research Center	UPRC	GR	
9	Palacky University Olomouc, Faculty of Science	PUO	CZ	
10	Westport Consulting	WPC	BA	
11	National School of Political Studies and Public Administration	SNSPA	RO	
12	Institute for Structural Research	IBS	PL	
13	Aalborg Universitet	AAU	DK	
14	PT Sustainability and Resilience	Su-Re.Co	ID	
15	Eco-union	Eco-union	ES	
	International Partners			
16	University of Greenland	Ilisimatusarfik	GL	
17	Innolab Space Canada – Center of Urban Transitions	Innolab Space	CA	
18	Swinburne University of Technology Australia	SUT	AU	

Executive Summary

There is a common understanding among academics for the need of a large-scale disruptive and rapid change of the energy system and the economy in general to meet the temperature targets of the Paris Agreement. For these targets, our energy system and industrial activities must be net carbon-neutral by 2050. This implies that Europe's future energy system will have to rely entirely, or almost entirely, on renewable sources, and completely phase out fossil fuels. Whereas the transition to renewables in general may have many economic upsides, many regions will, at least initially, be negatively affected by climate policy. The transition to a climate-friendly future strongly affects and even threatens to undermine the economic prosperity and social fabric of regions currently depending on coal or the carbon-intensive industries that need to be transformed or closed to reach carbon-neutrality. Efforts to minimise these adverse social and economic effects and help affected regions adapt to a low-carbon but still prosperous future will be key to the success of the energy transition and help to build public acceptance.

The term *tipping point* has gained popularity across multiple disciplines over the last decades: predominantly in climate science to anticipate when a complex system shifts abruptly from one state to another. Human systems also experience tipping points, sometimes involuntarily and sometimes as the result of deliberate actions. Here, we develop the tipping point concept and adapt it to social, socio-technical, or socio-economic systems to increase our understanding of how to manage transition processes in regions depending on industries that must end, or radically transform, due to climate concerns. It is particularly important that negative social and economic trajectories are avoided, and interventions to move them onto new, positive trajectories identified.

As part of the Tipping^{+} project, we conducted a literature review from a policy and governance perspective, investigating how deliberate interventions affect the emergence of social tipping points in coal- and carbon-intensive regions. Specifically, we investigate which interventions may support tipping processes in which social, political and economic contexts in an interdisciplinary integration of insights from many disciplines, including political science and public policy analysis, but also anthropology, psychology, cultural studies, geography and economics.

In the literature, and across different disciplines, tipping points are considered as a moment or period in time when a system rapidly shifts from state A to a qualitatively different state B. This characteristic has spurred significant scientific interest to understand and predict tipping processes in order to avoid crossing these thresholds and putting societies as risk (e.g. climate system tipping). The interest mostly translates to influencing political decisions and developing or changing policies to intervene in human behaviour, which may directly affect the tipping point itself (in a social system) or it may affect either the impact (e.g. climate adaptation) or likelihood or severity (e.g. climate change mitigation) of a natural system tipping process. Only recently has scientific attention been turned to social tipping points that are more than the adaptation to changes in the natural environment: how can we turn currently negative social or economic developments to positive ones?

The tipping point concept has found increasing application in three branches of literature with the first two relating to environmental impacts and the third solely focusing on social interactions. In this literature, three overarching themes emerge:

- Tipping points are a moments of discontinuity occurring within a specific context triggered by the conjunction or alignment of developments, so that the system fundamentally, qualitatively and (in some cases) irreversibly changes its structure and future, governed by new feedbacks;
- There are desired and undesired tipping points having specific positive or negative consequences for human societies, while undesired tipping points have found most attention in the literature so far;
- Because tipping points bring about rapid systemic change, there is an increasing interest to further understand how tipping points may be triggered to accelerate the transformation of social and economic systems.

Although the notion of social tipping points is new, the concept behind it has been investigated by social scientists with other terminology, using concepts and theories such as critical junctures, path dependencies and external shocks for many decades. These theories highlight the great complexity of social dynamics and point to the importance of considering multiple dimensions, levels and scales in the analysis of these societal processes. The causality of events and the apparently trivial fact that "timing matters" are crucial elements for investigation of change processes. Particularly the sequence of events "what happens when and in which order" is causally important since actions from the distant past can initiate chains of causation that have effects in the present. The role of actors and agency also strongly resonated in the literature, emphasised for example in transition management studies and collective actions of social movement actors. Also, governance interventions are important elements to change the direction and the pace of sustainability transitions.

Building on the literature, we define tipping points as a discontinuity in the development trajectory of a system, at which the system fundamentally changes its structure and dynamics. For identifying those tipping points we propose an analytical framework which comprises four aspects: tipping event (e.g. closing a mine); social, political and economic context; interventions to transform the system and bring about a tipping point; and the impact, describing the outcome after a tipping point happened. These are interrelated in the way that a tipping event disrupts the social and economic structure of a region, which leads to a desire to intervene and improve the development. These interventions may trigger a tipping point onto a positive trajectory, which can be observed as a qualitative change in the social and economic context conditions over time. We suggest indicators for each dimension and a set of guiding questions for analysis.

Our report is to be understood as a first step towards a deeper understanding of social tipping points and as a suggestion for indicators to be used in empirical case study analysis. The indicators presented here will be consolidated with the indicators from further Work Packages of the TIPPING$^+$ project and tested in selected cases. Following this, we will update the set of indicators based on the experiences from these case studies, before they are applied to a larger set of case studies in various Work Packages of TIPPING$^+$.

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1 Introduction

There is a common understanding among academics for the need of a large-scale disruptive and rapid change to limiting global warming to 1.5°C through reaching 80% zero-emission energy by 2030 and 100% by 2050 [1]. This implies that Europe's future energy system will have to rely entirely, or almost entirely, on renewable sources, and a practically complete phase-out of fossil fuels. Whereas the transition to renewables may have economic upsides and drawbacks, many regions will, at least initially, be negatively affected by climate policy – namely regions, whose economic situation currently depends on single coal- or carbon-intensive industries. The transition to a climate-friendly future strongly affects and even threatens to undermine the economic prosperity and social fabric of these affected regions. Efforts to minimize these adverse social and economic effects and help affected regions adapt to a low-carbon but still prosperous future will be key to the success of the energy transition and help to build public acceptance.

Shifting to a new system is a central focus of transition research and has been on the research agenda for several decades. The sustainability transitions refer to large-scale societal changes, deemed necessary to solve "grand societal challenges" [2]–[4]. 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. The climate challenge is without doubt such a transition, for which, incremental improvements are inadequate [5] and rapid and complete systemic transitions from today's carbon-intensive arrangements to entirely carbon-neutral ones are required [6]–[8].

Often, systems are assumed to respond to change in a smooth way. For the energy sector, policies and scientific of consultancy modelling represent the transition as a gradual change from today's system to a carbon neutral one, without step changes, collapses, or other types of game changing events [9], [10]. The tipping point thinking, applied to social, socio-technical, or socio-economic systems may seem either radical – systems don't change that easily! – or wishful thinking. However, complex systems often have critical thresholds – "tipping points" – "at which the system shifts abruptly from one state to another" (Scheffer et al. 2009, 53). All the big socio-economic and socio-technical systems we have today were once different – at some point in time, all existing systems tipped, became entrenched into the "normality" that we know today. Very likely, as past transition happened, things likely appeared to changes smoothly and slowly but then rapidly tipped into entirely different states in a sort of ketchup effect: first nothing seems to happen, then still nothing seems to happen, and suddenly everything happens at the same time. At some point in time, the currently existing complex socio-technical and socio-economic systems that developed over decades and centuries passed a tipping point, irreversibly changing them from their old to their current states.

A classic example is the transition from horses to cars as the main base mode of transport. We did not always have cars, but at some point in time, maybe 70-100 years ago, the car-based system started to entirely replace the horse-based transport system, and the transition became irreversible: today, it is unthinkable that horses will come back and replace the car [11]. This mobility change provided a number of benefits such as individual independence, flexibility and increased range

and speed of movement. It also created a set of adverse effects, which we try to solve today, almost a century later, such as dependency on petrol and diesel, pollution and CO_2 emissions, street congestion.

Further examples are related not only to the affected industry but to how entire sectors or societies adapt, and may pass a tipping point. A key driver of industrialisation in Europe was the establishment of textile industries. In Western Europe, these sectors peaked after World War II; for example, 700,000 persons (of the about 50 million citizens) worked in the West German textile industry in the late 1960s. In the following decades, the European textile industry faced pressures from globalisation and foreign competition, and almost the entire industry was lost especially to Asian countries; today, less than 30,000 Germans work in the remaining, exclusively high-end, textile industry [12]. Today, it is very unlikely that German textile companies will be able to compete with Asian firms: the system appears to have irreversibly tipped into a new state. Importantly, however, Germany adapted: the disappearance of the very important textile industry did not disrupt its economy or the societal fabric. At some point in time, the industry and society managed to transform, to move people and value creation to new sectors, where German industry was competitive.

These examples indicate that tipping points can be found in various transition processes yet it remains unknown what specifically triggers these processes. Undoubtedly, transitions are influenced and often determined by deliberate political, economic and civil society actions. Often, policy actions seek to trigger such new developments, to transform a region into a new social and economic future; the EUR40 billion spent by the German government to transform coal-dependent regions during the phase-out of coal are a prime example of this [13]. However there is a paucity of information about concrete sustainability interventions or leverage points [14]. This is particular the case for transitions that are "moving away" from something [15], but there is much insight about how create the regime for new socio-technical systems [16]–[18]. Hence, we know about how to get away from coal, and how to build up a renewables-based electricity regime. However, we know only little about how to transform societies around coal to a coal-free future, and yet this process can be very dramatic for local communities. Policymakers frequently talk about a "just transition", for example as defined in the Paris Agreement [19], but rarely mention how exactly this is going to happen.

Box 1: Social tipping points in sustainability transitions

Tipping points exist in both natural and human systems. The anticipated tipping processes in the climate system have triggered societal transformations, such as climate policies to mitigate avoid the worst impacts for human societies and adapt to inevitable ones. Such policies can however also put regions and communities onto undesired socio-economic trajectories, for example by requiring the closing of a factory or mine. Hence, the societal changes required for sustainability transitions may have serious negative consequences for currently coal- and carbon-intensive regions. A better understanding and insight are needed for how to shift these regions onto new, positive trajectories – climate-friendly and still prosperous. This report focusses on social tipping points and the interventions that may trigger them.

As part of the Tipping+ project, we address this research gap by reviewing research from a policy and governance perspective in relation to decision-making processes and factors affecting the emergence of social tipping points in coal- and carbon-intensive region. The aim of TIPPING+ is to identify, characterise and carry out empirical analyses to advance the state of the art on both negative and positive tipping points supporting the transformative capacity of regions as well as advancing Transition Theory. In this report, we examine different strings of research from several different disciplines and their concepts and insights about policy interventions in transitions and (regional) crises, so as to be able to better analyse interventions and their effect in the emergence of social tipping points in coal- and carbon-intensive region. In fact, "tipping points" have great political relevance and a wealth of literature has emerged in the last decades. In addition, the notion of "tipping points" refers to many classical theories in political and economic science that are concerned with issues of institutional transformation, lock-in effects, path dependency, critical junctures, regime destabilisation and collective action for change.

The literature review constitutes the basis of the case study research providing a guiding framework for analysis. The overall research question is which interventions in which contexts trigger tipping processes?

To answer this question the literature review is structured into three main parts:

- A systematic review of the wide-ranging literature on tipping points aiming and exploring it from policy perspective and capturing the main discourse on tipping point interventions;
- An investigation of models and theories which capture the notion of tipping points.
- A proposal for an analytical framework with context and intervention indicators for the case study analysis from policy perspective

2 Literature review

Everyone has experienced various types of tipping points in their lifetime, on all scales, from the smallest, personal level to the largest, global level. Tipping points can be personal, such as marriage and divorce, or simply the process of entering puberty. They can be national, such as the re-unification of Germany after the fall of the Wall. Or they can be global, such as the increasing dissatisfaction and economic downturn in the former East Bloc leading to mass protests, economic collapse, and ultimately the demise of the entire Soviet Union.

Because tipping points have dramatic effects, they are also a topic in academic research. In biophysical systems research, such as climate science, tipping points have received broad attention and is today a generally accepted scientific concept [20]–[25]. There is also a consensus that such tipping points are serious threats to humans and human systems, requiring substantial efforts to both adapt to new conditions and to avoid the worst anticipated impacts happen. In consequence, not only natural systems may tip, but human systems may also tip because of transformations needed to adapt to the new state of the environment, or transformations needed to avoid the worst anticipated impacts. For example, climate tipping points such as permafrost melting or the halting of ocean currents, would gravely affect the regional and global climate. This, in turn, would affect societies that were built up and adapted to a particular climatic regime. These societies would then need to undergo rapid societal change both to mitigate such effects and to deal with inevitable consequences are necessary [23], [26]–[29]. These rapid transformative social changes may – intentionally or unintentionally – fuel social tipping processes: societies depending on industries that must end due to climate concerns may be propelled onto negative social and economic trajectories, so that efforts to instead move them onto new, positive trajectories are needed. For example, climate change mitigation requires the phase-out of coal, which will have strong effects in regions that depend on coal for their economic prosperity. Hence, the effects meander through nature and society, so that the risk of interrupting Atlantic Ocean currents in the future requires us to think about what to do with coal-rich Silesian cities today.

As we show below, research on biophysical tipping points has been formalised and grounded in substantial wealth of studies in the last two decades, the latter two types – tipping points in human-environment systems and social tipping points – are not yet broadly applied and accepted concepts, although there is both theoretical and empirical research de facto focusing on tipping points, but with other foci and terminology.

2.1 Bibliometric analysis

The term *tipping point* has experienced explosive popularity across multiple disciplines over the last decades. A simple Google Scholar search in October 2020 provided 360,000 results (see Table 1). Similarly, an entire document search for the term in academic databases such as Scopus resulted in 34,709 and in Base provided 45,392 hits.

Table 1: Results from searching in Google Scholar

Key words	Results
Tipping AND point	More than 360,000
Tipping AND point AND policy	More than 217,000
Social tipping point	More than 208,000
Tipping AND intervention	More than 110,000

Across the literature, a tipping point is considered as a moment when a system rapidly shifts from state A to a qualitatively different state B. This characteristic has spurred significant public interest to understand and predict tipping processes in order to avoid crossing these thresholds and pushing societies onto undesired trajectories. The interest mostly translates to influencing political decisions and developing or changing policies to intervene in human behaviour, which may directly affect the tipping point itself (in a social system) or it may affect either the impact (e.g. climate adaptation) or likelihood or severity (e.g. climate change mitigation) of a natural system tipping process.

Our literature review and especially the key word search confirmed that there is a policy element in most studies and papers about tipping points, and this policy relevance is often the purpose of the study (see Table 4). Despite the apparent policy relevance of tipping points, the concept has not received particular interest in political science journals other than a very generic use of the term 'tipping point' (Table 2).

Table 2: "Tipping points" in selected political science and policy-focused journals

Journal	Time	No. of articles (Title, abstract key words)	No. of articles (In ALL)
American Political Science Review	2000-2020	0	129
British Journal of Political Science	2000-2020	0	85
Global Environmental Change	2007-2019	0	45
Renewable and Sustainable Energy Reviews	2005-2021	3	19
Environmental Innovation and Societal Transition	2011-2020	1	18

Journal	Time	No. of articles (Title, abstract key words)	No. of articles (In ALL)
Energy Research and Social Science	2014-2020	1	28
Energy Policy	2011-2020	4	29
Political Geography	2010-2020	1	7
Policy and Society	2000-2020	1	6

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Tipping points are very much an interdisciplinary topic which received great attention from various disciplines in the last century. For example, one of the first and most cited publications on the topic is Malcom Gladwells's book "The tipping point: How little things can make a big difference" (2000) with 11.852 citations in Google Scholar, in which he described common life situations and revealed tipping points when an idea, trend, or social pattern may suddenly spread like wildfire. The tipping point field is characterised by this interdisciplinary tradition, and researcher from natural and social science have frequently expanded the topic by borrowing and extending ideas, approaches and frameworks used in other contexts, both through theoretical work and empirical studies.

A systematic key word search in databases and digital libraries such as Scopus, Base and JSTOR revealed a distinction of the literature into three branches: biophysical tipping points, human-environmental tipping points and social tipping points (see also next section). For example, the year 2020 Scopus comprises 101 results from a key word search "tipping points" in social science.

Table 3: Keyword search in JSTOR and Scopus

JSTOR		Scopus	
Search mask	Results	Search mask	Results
In all fields 2000 – 2020 In articles	10,424	KEY (tipping AND point) AND (PUBYEAR > 2000) AND (PUBYEAR < 2020) AND (LIMIT-TO (DOCTYPE , "ar"))	19,093
In all fields Political science 2000 – 2020 In articles	1,435	TITLE-ABS-KEY (tipping AND point AND policy* OR "transition") AND (PUBYEAR > 2000) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "SUBJAREA (Sociology and Political Science)") OR LIMIT-TO (DOCTYPE , "English") OR LIMIT-TO (DOCTYPE , "SOCI OR LIMIT-TO SUBJAREA"))	691
In all fields Public policy 2000 – 2020 In articles	290	KEY (tipping AND point) AND (PUBYEAR > 2000) AND (PUBYEAR < 2020) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SUBJAREA , "SOCI"))	101

JSTOR		Scopus	
Search mask	**Results**	**Search mask**	**Results**
In abstracts and title 2000 -2020 In articles	15	TITLE-ABS-KEY (tipping AND point AND policy* OR "transition") AND (PUBYEAR > 2000) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "SUBJAREA (Sociology and Political Science)") OR LIMIT-TO (DOCTYPE , "English") OR LIMIT-TO (DOCTYPE , "SOCI OR LIMIT-TO SUBJAREA")) AND (LIMIT-TO (SUBJAREA , "ENER"))	30

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2.2 Three literature branches of tipping points

In the last 150 years, a range of different concepts, ideas and theories describing small changes with large systemic effects has been developed, especially within natural science and at the intersection of natural and social sciences [30]. 'Tipping' was used originally in the industry referring to a point at which a rail wagon of coal or a cup in a tilting water meter, tipped over and emptied its contents [31], [32].

Three branches of literature have been identified with the first two relating to environmental impacts and the third solely focussing on social interactions (see also Table 1):

- Tipping points in biophysical systems and their impacts on other biophysical systems (climate or ecosystems);
- Human-environmental tipping points describing environmental dynamics which lead to socio-economic dynamics and have (mostly adverse) impacts on human societies;
- And social tipping points relating to socio-economic or socio-technical developments and their transformative impacts of societies.

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

- Tipping points are a moments of discontinuity occurring within a specific context triggered by the conjunction or alignment of developments (or variables), so that the system fundamentally, qualitatively and (in some cases) irreversibly changes its structure and future, governed by new feedbacks;
- There are desired and undesired tipping points having specific positive or negative consequences for human societies, while undesired tipping points have found most attention in the literature so far;
- Because tipping points bring about rapid systemic change, there is an increasing interest to further understand how tipping points may be triggered

to accelerate the transformation of social and economic systems.

We describe and discuss each of the three branches of tipping point literature below and summarise the key elements in Table 1.

Table 4: Views on tipping points in the three main literature branches

	Biophysical tipping points	Human-environmental tipping points	Social tipping points
System of reference	Climate system, biodiversity, ecosystems	Ecosystems, economy and social systems	Social systems, institutions, technologies and infrastructure, economy
Change patterns	Macro or micro dynamics in biophysical systems leading to qualitatively different state(s) of the biophysical system(s)	Human-environment interactions where ecological change (including biophysical tipping points) triggers rapid change to qualitatively different state of a social system	A sudden shift from one regime dynamic to another e.g. uptake of ideas, technologies, behaviours or new or failing institutions
Examples	Climate system: a strong ocean current becomes a substantially weakened Ecosystem: oligotrophic lake state – good water quality tips to eutrophic lake state with 'poor' water quality	Overgrazing of livestock, reducing the ecological carrying capacity, leading to loss of future herding opportunities, knowledge and cultural identity; affected society must adapt, transform or move away.	Regime shifts leading from peace to war, democracy to autocracy Reunification of Germany followed by socio-economic disruptions in East Germany Anti-nuclear mobilisation and the abolishment of nuclear power
Mechanisms	Large-scale human induced processes (e.g. CO2 emissions) triggering (internal) positive feedback loops within a biophysical system	Human-induced biophysical processes (e.g. loss of biodiversity) triggering self-reinforcing feedback loops within biophysical and human systems (e.g. loss of fishing knowledge, no investments in fishing	Human interactions and interventions triggering thresholds in political-institutional, economic, technical and social systems

	Biophysical tipping points	Human-environmental tipping points	Social tipping points
		assets etc.)	
Temporal dynamic	Medium- to long-term lead up process (e.g. global warming since industrialisation) with (relative) rapid change after the tipping point(s)	Short- to medium-term lead up process (e.g. overgrazing) with rapid change compared to typical processes in social and ecological systems	Short- to medium-term lead up process (e.g. mobilisation or racial segregation) with rapid change compared to typical processes in social systems
Impacts	Irreversible on macro and medium level of biophysical systems – original state cannot be restored (through human actions, on human timescales)	Creates (often) adverse changes for human livelihoods (socio-economic dimension)	Can create normatively perceived positive or negative trajectories for human societies, which can lead to new path dependency and institutional lock-in effects
Policy relevance	Forecast tipping points, and inform about "safe levels" of climate change or ecosystem change	Assessing the costs, increase resilience and manage adaption, accelerate transformation	Offset adverse socio-economic impacts and mediate between different societal groups, accelerate transformation

2.2.1 Tipping points in biophysical systems

In the last 15 years, natural scientists have formalized the concept of 'tipping points'. Indeed the bulk of studies and publications on 'tipping points' stem from this branch of literature.

A tipping point is used to refer to a situation in which a biophysical system experiences a drastic and irreversible shift to a new state causing significant changes to its physical dynamic, biodiversity or ecosystem services [21], [33], [34].

Lenton et al. (2008) describe climate tipping points as "critical thresholds triggered by small perturbation leading to nonlinear responses in the internal dynamics and consequently altering large-scale components of the Earth's climate system". The authors identified several 'tipping elements' in the climate system that could pass a tipping point this century, leading to a qualitative change in their future state [21], [35]. Classic examples are: the abrupt loss of Arctic summer sea-ice, irreversible meltdown of the Greenland ice sheet (GIS), disintegration of the West Antarctic ice sheet (WAIS), reorganisation of the Atlantic thermohaline circulation (THC), increased amplitude of the El Niño Southern Oscillation (ENSO), disruption of the Indian summer monsoon (ISM), collapse of the West African monsoon (WAM),

dieback of the Amazon rainforest, and dieback of boreal forests. Lenton (2011) also emphasises that there can be multiple causes tipping biophysical systems, which cannot always be related to global warming or CO2. For example, the Indian summer monsoon is weakened by localised aerosol pollution, both cooling sulphate and warming black carbon aerosols, which form 'atmospheric brown clouds'.

Forests, lakes, coral reefs, oceans, and arid lands are also exposed to gradual changes though studies have shown that these can be interrupted by sudden drastic switches to a contrasting state [20], [33], [34], [36]–[39]. Ecological tipping points are also investigated as 'critical transitions' causing 'regime shifts' in biological or ecological systems. For example a species whose population drops below a specific threshold will move onto a trajectory leading over time to extinction. Vegetation shifts caused by climate change induced prolonged droughts, such as desertification in the Sahara [40], or increasing CO2 concentrations may shift coral reefs to entirely different ecosystems [41], [42]. Climate change also exacerbates local stresses from declining water quality and overexploitation of key species, driving reefs increasingly toward the tipping point for functional collapse [38], [41].

Studies on climate and ecological thresholds and tipping points play an important role to bridge the science–policy interface. These investigations provide particular knowledge and understanding about threshold-based environmental changes leading to adverse impacts. Hence they help to inform policy makers and create a platform for a salient and credible dialogue between decision-makers and scientists about the amount of acceptable change, when unacceptable conditions could occur, how likely these conditions are and what adaptation pathways to consider [43]. Identifying and quantifying planetary boundaries that must not be transgressed could help prevent human activities from causing unacceptable environmental change while creating and maintaining a 'safe operating space' [26], [44]. A key driver is the growing and critical interest to forecast the future states of ecological systems and the continuous availability of critical services such as food, fresh water and flood controls [45].

2.2.2 Tipping points in human-environment systems

A growing bulk of research linking ecosystems and social science is emerging from in the socio-ecological approach of transition research. Here, scholars seek to identify critical thresholds in the complex interactions between the human society and biophysical systems to avoid undesirable transitions.

The focus of this branch of literature is how the climate or ecosystem changes (human or naturally induced) have social and economic impacts. For example, Fernández-Giménez et al. (2017) find that Mongolian steppes are close to ecological and cultural tipping points based an analysis of time series data for climate, vegetation, livestock and human population. They claim that rural-urban migration leads to loss of pastoral cultural and place identity, values and traditional ecological knowledge. They apply 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".

Another study by Franklin and Pindyck (2018) have investigated the implications of a forest-savanna critical transition and calculated the social costs of deforestation.

Indeed, a growing number of studies are coming from environmental economists. Models have been developed to calculate the risks and costs of tipping points for ecosystems in response to changes in e.g. rainfall patterns, depletion of resources and deforestation. It was found that a failure to address them can lead to a spiral downwards towards a state of marginal sustainability, and interventions such as payments for ecosystem services are necessary to ensure continued provision of global benefits from intact ecosystems [21], [46], [47].

Similar to biophysical literature the political interest lies in predicting ecological thresholds [48] but moreover in managing and controlling systems to avoid undesired trajectories. For the latter studies highlight questions about the resilience and the capacity of the actors in a system to manage resilience with intent and so successfully move towards desirable trajectories [48]–[51]. Resilience is the capacity of a system to experience shocks while retaining essentially the same function, structure, feedbacks, and therefore identity [52], [53]. Kopp et al. (2016) find that harmful social tipping points are more likely to occur where there are low levels of societal resilience, under which societal risks increase because of failure to effectively adapt or mitigate.

In this branch of literature, studies place different weights on the ecological or social dimensions of change and their related tipping points. Hence a strict separation from literature on social tipping points is somewhat difficult. This applies in particular to the fact, that intervention to avoid climate or ecological tipping points can trigger societal change and lead to a cascade of social tipping points. For instance, some proposed mitigation and adaptation measures such as phase out of coal are so transformative that their implementations can be considered an social ecological tipping point in terms of 'response to climate change' [54].

The social dimension is for example a strong focus in López et al. (2019) study. They conducted a transdisciplinary case study to identify tipping points in the Jordan River region, an area of severe conflicts and environmental problems. Through an extensive stakeholder engagement involving multidisciplinary group of scientists and regional stakeholders evaluated emerging ecological and social tipping points providing recommendations for sustainable management of natural resources in this highly contentious area, crossing different cultural, political, and socio-economic conditions.

The social dimension is also a focal point for Tàbara et al. (2020) who recently introduced the concept of Social-Ecological Tipping Points. The authors apply their concept in two regional case studies in order grasp some of the complex and coupled dynamics of positive changes in social-ecological systems. Through a social-science lens they investigated the emergence of new narratives, capacities and collaborative strategies which enabled the local deployment and acceptance of renewable energy systems. An important difference to the biophysical literature is the emphasis on so called 'positive tipping points' [29], [56], [57], which describe a normative perception of a desired trajectory in terms of sustainability transformations. Indeed this and related works have many links and cross-overs to the social tipping points literature [23], [29], [58]–[60].

2.2.3 Social tipping points

Like climate and ecological systems that experience sudden shifts, social and economic systems can also encounter tipping points [30], [57], [58], [60], [61]. The third branch of literature is concerned with the notion of social tipping points – referring to fundamental shifts within socio-political, cultural, economic or technical systems.

Major watersheds in societal life are commonly perceived as revolutions, wars or other large-scale events such as market collapse and major accidents. Hence the idea of tipping points is not new to social scientists though often capture in studies on thresholds, critical junctures or leverage points [14], [62]–[66].

Originally, Grodzin (1956) and Schelling (1978) applied the phrase describing tipping processes in studies of neighbourhood segregation in the US in the 1950s. Grodzin (1956) used the notion of 'tip points' to a critical proportion of non-whites in a neighbourhood, above which the fraction of whites precipitously declines to zero. In the following years the concept was further developed by economists and urban sociologists such as Eleanor Wolf (1963), Thomas Schelling (1978) and Jonathan Crane (1991) on similar social phenomenon. Schelling (1978) specially emphasised two key characteristics of a social tipping point as being a process that disturbs an original equilibrium and leading to an accelerated and irreversible change. Eldredge and Gould (1972) distinguish phases of policy change and stability in terms of 'punctuated equilibrium'. Gladwell popularised the concept of 'tipping points', exploring contagion effects ("fads and fashions"), sometimes triggered by specific events in his book "The Tipping Point: How Little Things Can Make a Big Difference" (2000). Importantly, and unlike Schelling, Gladwell does not focus solely on the tipping point of a phenomenon, but on the actual process that brings it about. For him, the process is made up of three interrelated parts: the "law of the few", the "stickiness factor", and the "power of context".

In 2012, Moser et. al. (2012) took the work of Gladwell as the starting point to investigate urban tipping process of violent conflict in developing countries. Based on several case studies the authors analysed the transformation of urban conflict into large-scale collective violence triggered when a combination of quantitative and/or qualitative factors alters the status quo of the urban environment (the steady level of conflict) and facilitates the spread of a phenomenon (a specific kind of violence such as youth violence) through the urban setting – significantly changing that environment in the process. Moser et al. (2012) found that the spread of this phenomenon proceeds through the urban setting at varying speeds, yet it is only when a "conflict tipping point" is reached that large-scale change occurs.

International relations scholars have also applied the concept of tipping points. For example Cao et al. (2013) used the notion of thresholds to assess the effect of trade on human rights practices. Their study provides evidence that trading relationships can, under certain conditions serve as 'transmission belts' for the diffusion of human rights standards from importing to exporting countries. Reus-Smit (2011) analysed expansion and globalisation of the European sovereign states model in different waves starting with The Westphalian settlement to other countries. He stresses the importance of subject peoples' struggles for the recognition of individual rights and finds that a "tipping point" was reached when the imperial system in question proved

incapable of accommodating the new rights claims and when the sovereign state was seen as the institutional alternative to empire.

Social shifts that are investigated by political scientists and sociologists also deal with shifts at the state or society level and include for example the transition from peace to war, from a stable state to a collapsed state or from an integrated to a segregated society. For example, Grimm and Schneider (2011) analysed social tipping points as constellations where the social fabric of a country breaks apart and where a country embarks on a course of dramatic, but not always violent political change. Similarly, Kuran (1989) analysed political revolution in terms of tipping dynamics investigating sudden shifts in collective sentiments which led to fundamental transformations of the social order drawing on examples of the Iranian, the Russian and the French Revolution.

Given their far reaching societal consequences (war, outbreak of violence etc.), Grimm and Schneider (2011) strongly contend that explaining and anticipating the process of when a state, region or society embarks onto a social tipping point is of utmost importance. Similarly to the other two branches of literature policy makers are interested in "real life forecasts" and thus anticipations of events that have not yet happened (Game Theory approach). This is accompanied with the development and use of forecasting models and evaluation tools in order to determine how varying policy choices are able to reach their goals ex ante. Indeed, preventive political action is less costly than reactive political action, not only in financial terms but also in terms of human lives [72]. Studies of fragile states demonstrate that most dramatic policy changes were almost always preceded by implicit or explicit negotiations between the conflict parties [72]. Hence the element of agency and deliberate intervention in social tipping processes appear as a strong indicator determining the trajectory of the social system. Focal points are social, economic and national security and international affairs policies.

2.2.4 Synthesis of the three branches

Many studies highlight the complexity of tipping processes which is further amplified when including socio-economic dynamics. Drawing on the literature review, we identified a number of pertinent issues and questions across the three branches.

Firstly, many researchers deal with the question if it possible to identify and explore tipping points ex ante or only ex post? In fact, the bulk of research aims at characterising critical thresholds and developing early warning tools in earth systems [28], [44]. However there are disagreements about the possibility and accuracy of identifying tipping points or thresholds beforehand [73], [74]. Indeed, early warnings of tipping points in social, economic and governmental activities are inherently more difficult to spot [75]. Drawing on biophysical system analysis, indications of whether a system is getting close to a critical threshold are related to a phenomenon known in dynamical systems theory as 'critical slowing down' [37]. Bentley et al. (2014) applied this theory on social tipping points and how this effect can be replicated in social and economic systems. They found that unlike natural or mechanistic systems approaching a bifurcation, there are no similar prediction methods for social systems. In fact, many social systems undergo tipping points without exhibiting warning signs. For example, they highlight the case of small English banks, which increased in number at about 2.7%/year for 150 years and then suddenly declined in 1810 with

no data indicating such a change was impending. Instead they encourage focusing on probabilistic insights from research on collective social dynamics. These approaches identify measurable qualities of social systems or networks, such as heterogeneity, connectivity and individual-based thresholds that make social tipping points more likely.

Tàbara et al. (2020) also note that social-ecological tipping points can be explained, albeit not necessarily predicted. Similar to critical moments or junctures, tipping points can usually only be identified retrospectively in reference to the specific historical legacy or systemic change [62], [63], [76], as tipping points produce specific development paths or trajectories. Similarly Fuchs and Thaler (2017) point out that only in retrospect, it is possible to properly describe shifts as being radical. We simply cannot know if present-day modification in dealing with hazard events will be seen in future as radical change in risk management strategies. This involves for example the development of a region in regard to e.g. economic growth and equality, employment, migration etc..

Ginkel et al. (2020) give two reasons for this central challenge to determine the tipping points which introduce regime shifts: (a) the complexity and dynamic character of the socio-economic system and (b) the fact that humans proactively and autonomously may alter the system. Social tipping processes can rarely be linked to a single common control parameter, such as is the case with global mean temperature in climate tipping dynamics. Nuttal (2012) concludes the sentiments of many scholars that social scientists can identify potential social tipping elements and associated mechanisms, though it is far more difficult to predict when they will occur. Yet, Grimm and Schneider (2011) argue that the risks for macro-events such as state failures can be "predicted" by a supplement use of three approaches– the *structural*, the *dynamic* and the *game-theoretic approach*.

Secondly, scholars and policy makers are increasingly interested in the potential of positive feedback processes to accelerating a shift to low-carbon energy systems while at the same time fostering positive socio-economic trajectories in affected regions. This culminates in the question about how to foster positive tipping points [29], [56], [78] allowing for desirable developments and impacts over time. As indicated by the adjective *positive*, there is a close connection between tipping points and a normative understanding of a desired future state of a system. Examples for such proposed social tipping dynamics include divestment from fossil fuels in financial markets, political mobilization and social norm change for sustainability and socio-technical innovation. Ginkel et al. (2020) and Young (2012) emphasis that these descriptions are subjective; whereas transformative change may pose opportunities for some stakeholders, it may be destructive for others, in particular those that depend on the established system. For example, a tipping transition to renewables is positive for environmentalists and the solar industry, but likely negative for the oil industry. In addition, systemic changes are subject to individual and collective perception and influence the labelling of a certain tipping point into positive or negative.

In general, positive tipping points can be associated with examples like the approval of the Charter of Human Rights or the abolition of slavery [56]. Kaaronen & Strelkovskii (2020) 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 practice including behaviour and cultural traits. In a socio-technical system the production and storage of energy is a key tipping element [23]. Another positive tipping point for example constitutes the endogenous and rapid transition to renewable energy sources [29]. The positive tipping points in a socio-economic system can be associated for example with positive trajectory in regards to livelihoods and configuration of the domestic economies, as well as education, resources and migration. For example Tàbara et al. (2020) found that a combined approach of introducing solar home systems, capacity building and social entrepreneurship in Bangladesh can trigger systemic effects and lead to many other positive effects on education, use of time and resources. They conclude that a positive tipping point is achieved whenever necessary and sufficient capacities have been built to implement the kinds of solutions/actions to achieve a transformative vision of the system, so that new desired system' conditions are created. Building on that, we suggest that positive tipping points in socio-economic systems bring qualitative improvement of individual or community life which includes e.g. higher (or not reduced) income, better (or not impaired) health, education and local economic development.

However the term "tipping point" is also used to describe non-linear "positive feedback processes" which constitute sources of increasing returns and self-reinforcing processes [18], [21], [63], [79]. For example Lenton et al. (2008) refers to tipping points and positive feedback processes triggering changes in the Earth Systems such as the melting of the poles sea-ice. 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" [18], [80]. Institutionalists and economists refer to increasing returns and "positive feedback" processes as path dependent processes, which suggest that a step in a particular direction generates a positive feedback loop, increasing the pay-off for additional movement in the same direction [81]–[84]. On the other hand, the negative feedback loop is associated with a lack of positive feedback or presence of barriers/forces against change while the normative understanding is decline and a downward trajectory in regards to societal welfare.

Thirdly, the spatial-temporal dimension in socio-economic dynamics is a particular challenge for identifying tipping points. Studies emphasise the importance of time frames – long or short term – and whether the spatial scope is localized or widespread. Since social tipping points are sometimes understood as a point in time, rather than a point in a complex parameter space [30], there is a risk of overlooking microscopic thresholds. Further, the detection of significant disruptions in certain indicators may require long time data series, otherwise causalities might be lost and only context specific changes might be observed. This particular implies methodological challenges obtaining long term data sets of certain indicators and identifying causalities. Mandel and Veetil (2020) also caution that models which shed light on long-term consequences will have to be somewhat different from those which explain short and medium term dynamics, at least in part because economic agents are likely to adapt to new circumstances.

Social transformations are dynamic nonlinear social process. The sequence and alignment of social decisions and developments are additional dimensions to consider in the analysis of tipping points. Some 20 years ago, Pierson (2000) already drew the attention to temporal ordering of events or processes, while highlighting that

time serves as a dimension that links together quite separate social processes in highly consequential ways (p. 55). He finds that that if two events or particular processes occur at the same historical moment, the result may be very different from when they are temporally separated. In addition, reaching one threshold can result in a cascade of tipping points across social, economic, legal and political systems [86]. Cascading effects can occur within the same system or between different systems originally presumed to be unconnected. However not all contagion processes escalate or lead to cascading effects, as this depends on the spread dynamics ratio (Tàbara et al., 2020).

A particular characteristic of tipping points is the abrupt change they may lead to. Ginkel et al. (2020) define abruptness in two ways: change is rapid compared to a geological timescale or rapid compared to a policy-relevant time horizon. Social tipping points such as the fall of the Berlin Wall in 1989, the collapse of the Communist Czechoslovak regime in the same year or the outbreak of the genocide in Rwanda in April 1994, have indeed occurred within a matter of hours. Though, Grimm and Schneider (2011) argue that in almost all cases, such shifts are the result of a longer term change in the social, political and economic order of a country resulting in the destabilization and (near) failure of the regime. Hence, this emphasises the need to observe longer term processes as well as the relevant structural, normative and behavioural patterns that contribute to the destabilization of a system the sudden tipping over of the relevant processes to new modes of interaction (ibid, 2011).

Fourthly, a growing number of studies are concerned with the possibility of intervening into tipping processes [23], [56], [87]. Winkelmann et al. (2020) identify two points of intervention: if a systems is already in a critical condition, where the stability of its current state is low, there may be a time window during which an agential intervention might prevent an unwanted tipping process by moving the system into an uncritical condition. Alternatively, if a system is not already in a critical condition, there may be a time window during which some intervention might move it into a critical condition in order to bring about a desired tipping process. In fact interventions can be particularly powerful if they drive the system into a new basin of attraction, making them difficult to reverse. In this circumstance, a small intervention can tip a system from one behaviour to another. Further, it points to the need to explore the (level of) criticality of a system to assess the potential effects (and perhaps occurrence moment) of a possible tipping event (without falling into linear probabilism).

Tàbara et al. (2020) similarly emphasises the potential influence of tipping points and the change created "through conscious and deliberate processes, and thus they are amenable to learning and purposeful action, usually articulated around narratives". They posit that there can be in fact *positive tipping points* which may be understood as "the moment in which both social and ecological systems together take new positive and intentional trajectories" (p. 4). 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" (Otto et al., 2020, Tàbara et al., 2020, Farmer et al., 2019).

Psychology and economic behaviours research have already shown that accumulation of effects due to social contagion, repetitive nudging, or direct intervention can lead

to social tipping dynamics [66], [88], [89]. This is suggested in for example Gladwell (1996) popular example from the New York subway cleaning, but is also referred to in other examples such as the findings of Crane (1991). He determined that a decrease in neighbourhood quality leads to a sharp increase in the probability that an individual will develop a social problem, in his case an increase of school dropouts and teen childbearing rates which was observed as a contagious dynamic when the number of workers with high-status jobs in the area decreased below 4%.

Hence, this suggests that influencing social tipping points through purposeful interventions could be a way to prevent or avoid undesired transition outcomes. In the analysis of Otto et al. (2020) governance and policy interventions play an important role. They define social *tipping interventions* as directed measures that "can activate contagious processes of rapidly spreading technologies, behaviours, social norms, and structural reorganization within their functional domains that we refer to as social tipping elements". For example they argue that adaptation and deployment of existing clean energy technologies is a key element of the decarbonisation process. 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 that are enabling this process are for example redirecting national subsidy programs to renewables and low-carbon energy sources or re-moving the subsidies for fossil-fuel technologies.

In another study, Tàbara et al. (2020) found that both hand market-based intervention with robust grassroot 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. Interestingly for their cases there was limited direct government intervention - in fact the programmes responded to a lack of or failure of government run programmes. Nonetheless they suggest government support could have resulted in longer-lasting positive interventions.

2.3 Transition and political literature and their views on tipping points

The notion of tipping points and the idea of threshold which can lead to significant societal change has been adopted in a number of political frameworks, theories and models such as critical junctures, punctuated equilibrium, path dependency and political opportunities. These theories highlight the great complexity of social dynamics and point to the importance of considering multiple dimensions and scales in the analysis of these societal processes. The causality of events and the apparently trivial fact that "timing matters" are crucial elements for investigation of change processes. Particularly, "what happens when" - the sequence of events is causally important since actions from the distant past can initiate particular chains of causation that have effects in the present. As Pierson (2000) suggests "small" events early on may have a big impact, while "large" events at later stages may be less consequential". The role of actors and agency also strongly resonated in the literature emphasised for example in transition management studies and collective actions of social movement actors. Also, governance interventions are important

elements to change the direction and the pace of sustainability transitions.

This part of the report gives an overview of these concepts and related dominant theories and models to extract their notion (and the key issues) in relation to social tipping points and interventions.

The first section places the concept within the transition literature and its application in MLP. The following section provides an account of several theories and their association with the notion of tipping points including historical institutionalism, social movement theory, and path dependency theory.

2.3.1 Transition literature and the multi-level perspective on socio-technical transitions

Sustainability transitions are characterised by inertia and dynamics of radical innovation which constitute the focus of the interdisciplinary field of research on 'sustainability transitions' [3], [5], [17]. These are broadly understood as qualitative changes in systems such as energy, food or transport that aim to address grand challenges in a way that meets the needs of the present without compromising the ability of future generations to meet their own needs [3], [8].

Over the last decades, the grand societal transitions have been investigated from multiple perspectives. Loorbach et al. (2017) identify three major lines of research: the socio-technical, socio-institutional and socio-ecological. The socio-technical perspective is the most well established field of transition research applied often through multi-level perspective (MLP) analysis 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 the research focus is on formal and informal institutional structures such as regulations, norms, cultures, and practices in which transitional change takes place. Studies are concerned with the creation and impacts of path dependencies and how these are challenged by social innovations. The third line concentrates on the interplay between ecological systems and societal contexts drawing on insights from biophysical science. Major explanatory frameworks emerged around the term "resilience" or "panarchy" [53], and the boundaries of ecological systems which are marked by "tipping points" leading to shifts from one dynamic equilibrium to another.

The transition research produced three distinct frameworks to analyse and address the characteristics of sustainability transitions: the Multi-Level Perspective (MLP), the Technological Innovation System approach (TIS), Strategic Niche Management and Transition Management [5], [16], [18], [90], [91].

Transition management involves the implementation of change through systematic planning, organizing and implementation of change in complex adaptive societal (sub-) systems [2], [92]. This concept is often presented as regime transformation guided principally by negotiation between social actors from beyond the regime [91] Franzeskaki et al. (2019) particular highlight the importance of actors and agency in their conceptual framework of agency's capacities for climate governance. They propose a nested perspective on governance interventions to intervene against expected disturbances and pressures (i.e. to adapt), to minimise the occurrence of

disturbances and pressures (i.e. to mitigate), to create radical innovations (i.e. to transform) as well as to create synergies between interventions (i.e. to orchestrate)[93]. From these four distinct governance interventions Franzeskaki et al. (2019) identify four corresponding agency's capacities: adaptive, mitigative, transformative and orchestrating capacities. These capacities are crucial dimensions for positive social tipping points highlighting a system's resilience and ability to promote sustainability.

The MLP has become one of the central approaches to explain and analyse transformation processes [90], [91], [94]. In fact, as MLP accounts for many aspects of societal and technological change simultaneously, it has been applied in many sectors, e.g. energy [16], [95], water (Brown and Keath, 2008), transport [4] and even the Covid pandemic [96].

In this model, socio-technical transitions are considered as non-linear processes describing developments on three analytical 'levels': socio-technical regime (the locus of established practices and associated rules), technological niche (the locus for radical innovations), and landscape. MLP suggests that slowly changing factors place pressure(s) on an existing regime, so that at a certain point a window of opportunity may cause a breakthrough of a niche innovation.

At the centre of the MLP stands systemic change, rather than single technology fixes or only behavioural change. It is a global model that maps the entire transition process and emphasises that there is no single cause or driver (e.g. technological innovation) for transition processes but instead multiple dimensions (technology, industry, markets, consumer behaviour, policy, infrastructure, spatial arrangements, and norms and cultural meaning) at different scales (local, national, international) which link up and reinforce each other ('circular causality'). In the MLP view, systems are inherently stable, because the regime is perfectly adapted to the current state. Transitions are rare, because radical innovations have a hard time to break into the existing regime. Unless the existing regime is weakened, either by landscape pressures (e.g. increasing knowledge about the climate effects of energy generation and a desire for strong climate change mitigation) or by niche innovations emerging and challenging the regime (e.g. solar PV becoming very cheap), it will remain "dynamically stable" and adapt slightly over time but not change fundamentally.

This is closely linked to the positive feedbacks leading to lock-in [79], in which technologically or economically superior solutions may be held back by positive feedback loops of infrastructure, practices, sunk investments etc. in the existing regime. It is leads to the "ketchup effect" mentioned earlier: as long as the prevailing positive feedback is not broken, the transition appears to not happen – until the feedbacks break and new positive feedbacks in support of the new system materialise.

In the MLP, the transition has "happened" when an existing regime has been broken up and reshaped in support of a new system. In this view, a transition is more than a "change": when the regime is reshaped, the system effectively changes from one state to a new one. This transition is thus the same as our view of a tipping point, although that term is rarely used. Instead, "reconfiguration" or "realignment" are common terms (describing slightly different types of transitions) used to describe the shift from one regime to another, i.e. from one highly structured socio-technical configuration to a new one [16], [90]. This framework has mainly been used to

analyse historical transitions, showing that socio-technical transitions only happen when developments at all three levels link up and reinforce each other. Classical examples include the transition to the car, for which the invention and improvement of the automobile itself were important but not decisive: the breakthrough came not when the car was invented, but as infrastructure, regulations and norms had changed sufficiently so as to allow the car to play out its strengths – speed, flexibility, range – and rapidly push the horse to the history books [97]. Similarly, the steam ship did not break through when the steam engine was developed, but in a process over several decades, driven by a desire to safely and reliably transport people and goods across vast distances – for which the creation of global (or Commonwealth-wide) coal distribution networks and infrastructure projects like the Suez Canal were pivotal; sail ships were initially faster, but coal ships navigated independently of the weather and could even travel on a fixed timetable, and as the infrastructure grew and the desire for predictability increased, the sail ships became obsolete [97]–[99]. Hence, characteristic of the MLP is the absence of linear cause-and-effect relationships or simple drivers and an emphasis of mutually reinforcing developments, (re-)alignments, co-evolution of technology and regimes, innovation cascades, knock-on effects, and hype-disappointment cycles..

The systemic reconfigurations needed for a socio-technical transition are enacted, reproduced, maintained and transformed by actors such as firms and industries, policy makers and politicians, consumers, civil society, engineers and researchers. The MLP approach suggests that transitions can be induced through rational action, as well as through changing interpretations or power struggles (Geels & Schot, 2007); importantly, transitions do not "happen", but are the results of actions, although not all actions must necessarily have been directed to trigger the specific transition. Detailed multi-level case studies show mixes of rational, interpretative, power based and routine actions. All three levels in MLP have a particular view on actors and their role in the transition. For example niche actors (such as entrepreneurs, start-ups, spinoffs) work on radical innovations that deviate from existing regimes, and as their innovations mature, they will also work to adapt or replace the existing regime; incumbent actors, in contrast, work to maintain the status quo [100]. Policy makers play an important role in purposive transition. Indeed they can support niche-innovations and introduce major policy change, and thereby also provide a form of solution to potentially accumulated tensions [101], [102].

However other authors have pointed to limitations of the MLP approach in particular regarding the element of agency and the (over) emphasis on niche-derived agency in transitions, the assumption of existing end-points and s-curve dynamics [103]. Others question if sustainable transitions are really as tractable to policy-makers as implied in some interpretations of the MLP [104].

Geels (2002) views MLP as an heuristic concepts to understand and analyse the complex dynamics of sociotechnical change. MLP is a particular lens that could indeed yield important insights for the general question of what is required to tipping a system to a low carbon trajectory. In this view, tipping has happened when the regime has changed and adapted to match the needs of the new system. Its description of the regime, created for socio-technical and not necessarily social transitions, is useful for our purposes: a regional transition from being, say, a coal-based to being a knowledge-based economy is hard precisely because the coal-based

economy has created sets of institutions, economic and political patterns centred on and adapted to the needs of coal, which may be different than the needs of another type of regional economy. Just as an energy transition is more than the mere replacement of coal with wind power and requires new infrastructures and governing institutions, the social and economic transition of a coal-dependent region requires structural changes in the region to allow for the emergence of new economic activities. Further, the MLP's view of the landscape is highly relevant for further investigation of tipping processes, because many of the higher-level processes (e.g. political ideologies, societal values and beliefs, general macro-economic trends) that influence which interventions are more likely to be implemented and which are more likely to be successful.

2.3.2 Critical junctures and path dependency

The notion of tipping points is not new and has been investigated by sociologists and political scientists in concepts and theories such as critical junctures, path dependencies and external shocks for many decades. A central research focus is the creation, change and decline of institutions which is captured in institutional, organisational and management theories. Indeed, institutions play an important role in the fabric of social life constituting the 'rules of the game' [83], [84]. They are multifaceted, durable social structures, made up of symbolic elements, social activities, and material resources (Scott 2014, p. 57). A key characteristic is their relative resistance to change (Jepperson 1991) giving stability to social systems across time and space (Giddens 1984). When institutions change or new institutions are formed, they can significantly alter existing systems and/or create new trajectories.

Historical institutionalism, in particular, provides accounts of timing, sequencing, and interaction of ongoing political processes for example in cross-national variation [62], [63], [76], [105]. A core claim is that "polities pass through certain founding moments or critical junctures that fix into place basic political orientation and institution" [106]. Scholars of rational choice relate to it, with the notion of 'punctuated equilibria' (Baumgartner and Jones, 1991).

This concept of critical junctures has been particular appealing for researchers studying political regime change since it focusses on the causal powers of both agents and structure complemented by a temporal dimension of shorter phases of fluidity and change alternating with longer periods of stability and adaptation. Hence this concept encompasses notions of tipping points. However there is a great variety of perspectives conceptualising critical junctures with different emphasis on characteristics of choice (element of agency), embeddedness in broader context (antecedent conditions), determined or unintended triggers, happening in short or longer periods of time, while always producing specific development paths or trajectories [62], [63], [76], [105]–[109].

Collier and Collier (2015) define critical junctures "as a period of significant change, which typically occurs in distinct ways in different countries (or in other units of analysis) and which is hypothesized to produce distinct legacies". Mahoney (2001) understands critical junctures "as periods characterised by plasticity and contingency when the choices of actors have an important impact on the development of more enduring political institutions and structures - key choices made during critical

juncture periods may become embedded in institutions and structures which have long run causal effects. Capoccia (2015) also emphasises the role of agents "which face a broader than typical range of feasible options and the notion that their choices from among these options are likely to have a significant impact on subsequent outcomes" (p. 6).

Collier and Collier (2015) provided a framework (Figure 2) in their comparative study of different types of labor movements, their role in the emergence of reform movements and the role of the state in eight Latin American countries. They analysed the critical juncture during which organised labor was initially incorporated into the political and legal system, in order to explore the impact of party systems on regime dynamics, where the party system is understood as the political institutionalization of class coalitions.

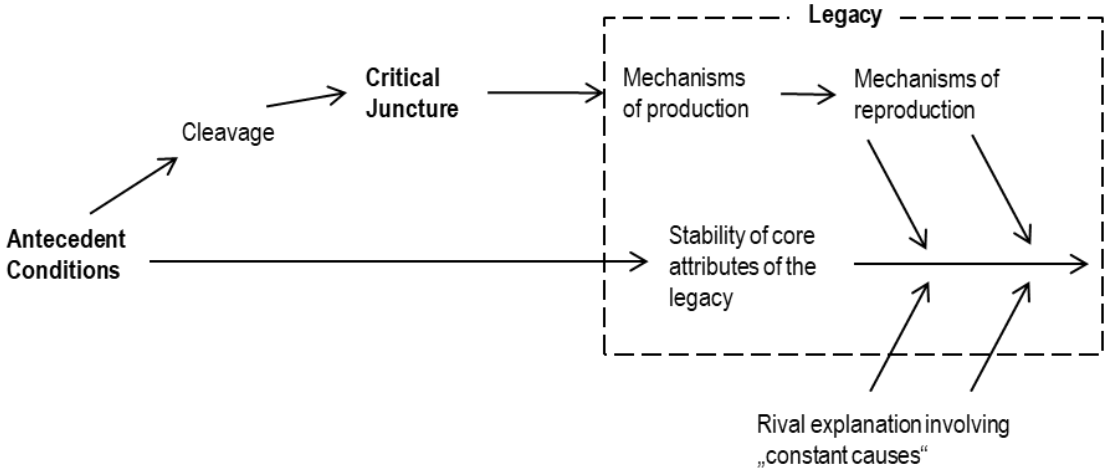


Figure 1: Building blocks of critical juncture framework

Source: Adapted from Collier and Collier, 2015, p. 30.

Here, critical junctures comprise three components: the claim that a significant change occurred, the claim that this change took place in distinct ways, and that the outcome or impact of a critical juncture produces a "legacy" – if not then one would assert that it was not, in fact, a critical juncture [62]. As shown in Figure 2 the individual components of the framework are: *antecedent conditions* that represent a "base line" against which the critical juncture and the legacy are assessed. In other words, a critical juncture happens in a certain context, which will change after a critical juncture passed and in fact determines if the juncture was critical. The so called *cleavage* (or crisis) emerges out of the antecedent conditions and in turn triggers the critical juncture. Finally the *legacy* which is the outcome of a critical juncture which consists of two mechanisms: a) Mechanism of production shaping the legacy through a series of intervening steps. b) Mechanisms of reproduction creating new stability perpetuated through ongoing institutional and political processes.

Though, a critical juncture may or may not have the potential to lead to a systemic transformation and they range from relatively quick transitions for example, "moments of significant structural change" to an extended period that might correspond to one or more presidential administrations, a long "policy period," or a prolonged "regime period." Critical junctures are often considered as an immediate

response to an external shock (e.g. war, financial crisis etc.) – and if so might be relative easy to spot since they occur more or less simultaneously across a number of countries. However, the political response even to such well-defined external events may occur quickly in some cases and be long delayed in others.

The distinctive contribution of the critical juncture framework is the differentiation between "historical causes" and "constant causes". Stinchcombe (1968) suggests that a constant cause operates year after year, with the result that one may observe relative continuity in the outcome produced by this cause. In contrast a historical cause corresponds to the intuitive understanding of critical junctures. In this case, a given set of causes shapes a particular outcome or legacy at one point or period, and subsequently the pattern that is established reproduces itself without the recurrence of the original cause. The latter is the particular circumstance which causes a tradition to start, while the constant cause is the general process by which social patters reproduce themselves. He referred to the example of the emergence and persistence of Protestantism in Northern Europe. Once the events of the Reformation had occurred, Protestantism perpetuated itself and did not have to be created or caused all over again by subsequent reformations (p. 102).

Similarly, Pierson (2000) posits "what makes a particular juncture "critical" is that it triggers a process of positive feedback" (p. 75). It suggests what David (1985) has called a "path dependent" pattern of change, in that outcomes during a crucial transition establish distinct trajectories within which, as he has engagingly put it, "one damn thing follows another" (p. 332).

Examples of critical junctures are the establishment of national constitutions, the process of state formation, the development and realignment of party systems, the commercialization of agriculture during modernization, and the process of labor incorporation into politics. Hacker (1998) finds that the similarity between all these examples is their fundamental impact on subsequent historical dynamics. "The ways in which these crucial periods of transition occurred shaped processes of political and economic development for decades to come."

Hence critical junctures are often link to the study of path dependency. Pierson (2000) summarised the claims of path dependency as: "Specific patterns of timing and sequence matter; starting from similar conditions, a wide range of social outcomes may be possible; large consequences may result from relatively "small" or contingent events; particular courses of action, once introduced, can be virtually impossible to reverse; and consequently, political development is often punctuated by critical moments or junctures that shape the basic contours of social life" (p. 251).

A relatable definition is provided by Margate Levi (2009) suggesting that "path dependence has to mean, if it is to mean anything, that once a country or region has started down a track, the costs of reversal are very high. There will be other choice points, but the entrenchments of certain institutional arrangements obstruct an easy reversal of the initial choice. Perhaps the better metaphor is a tree, rather than a path. From the same trunk, there are many different branches and smaller branches. Although it is possible to turn around or to clamber from one to the other—and essential if the chosen branch dies—the branch on which a climber begins is the one she tends to follow" (p. 28).

Unruh (2000) has applied the concept to the energy system and argues that industrial economies have been locked into fossil fuel-based energy systems through a process of technological and institutional co-evolution driven by path-dependent increasing returns to scale. This condition, termed carbon lock-in, arises through a combination of systematic forces that perpetuate fossil fuel-based infrastructures in spite of their known environmental externalities and the apparent existence of cost-neutral, or even cost-effective, remedies.

The path dependency theory has great relevance for tipping processes. To capture tipping points requires and understanding of the constraints that derive from past actions. Path dependency highlights that the sequence of events is causally important - actions from the distant past can initiate particular chains of causation that have effects in the present [112]. Further, better understanding positive tipping point processes in carbon-intensive-regions may help to answer the question of escaping carbon lock-ins.

2.3.3 Social mobilisation and political opportunity structures

The understanding that institutional forces create path dependence raises the question of how institutions change. One explanatory model is linked to the impact of social mobilisation and bottom up processes. Indeed institutionalists find that the theoretical considerations of social movement scholars provide useful frameworks to explain the institutional change (E. Armstrong & Bernstein, 2008; Schneiberg, 2013; Schneiberg & Lounsbury, 2008b; R. W. Scott, 2014). In fact, there are hundreds if not thousands of studies that emphasise the importance of movements and their ability to induce radical change through technology distribution (Heymann, 1995; K. H. Nielsen & Heymann, 2012; Sine & Lee, 2009; Toke, 2011). Hence, theoretical deliberations from the social movement scholarship hold important insights for understanding tipping processes as they may constitute the decisive intervention to tip a system towards a certain trajectory.

Since the 1960s social movement studies has grown into an established field of research, including a large body of literature on the definitions and characteristics of social movements (Diani, 1992; Eyerman & Jamison, 1991; McCarthy & Zald, 1977; Melucci, 1985, 1980; North, 2011; Porta & Diani, 2006; Saunders, 2013). Study objects were the environmental protection, civil rights and women's rights movements, which scholars analysed on how they influence and transform society (Porta & Diani, 2006; Zald et al., 2005). Social Movement Theory developed into several schools of thought, which can be categorised into two main streams focused on either structural or normative-cultural drivers of change (Corte, 2010). An important strand of the structural school of Social Movement Theory is Resource Mobilisation Theory, which emphasizes 'rational action and structural opportunities for movement emergence' and focuses on the use of resources to produce tangible outcomes or changes in (Bate et al., 2004; Porta & Diani, 2006). The cultural school of Social Movement Theory is the foundation of New Social Movement Theory, which is seen as a critical response to the resource mobilisation approach that emerged in the early 1990s (Seyfang et al., 2010). New Social Movement Theory emphasises in particular normative and cultural elements such as collective identity, values,

lifestyle and awareness of global issues as both drivers and desired outcomes of social movements (Melucci, 1980, 1985). Seyfang et al. (2010) points out that the strength of this approach lies in its 'ability to identify long-term transformations that create new conditions (structural, political, cultural) that can in turn stimulate the emergence of (new) social movements' (p. 10). Hence the framing of issues is an important component in order to challenge, disrupt and change existing arrangements (Benford & Snow, 2000). This is also linked to the central aspect of social movement theory, the existence of societal conflicts or politically contentious issues which are the triggers for mobilisation and collective action (Giugni et al., 1999; McAdam et al., 2002).

For example, Sine and Lee (2009) emphasise that social movements play a critical role in fostering nascent entrepreneurial activity in new sectors. They find that social movements can alter the norms and beliefs that underlie individual economic action and coordinate how individual actors allocate their time and resources. Thus, social movements can shape individuals' decisions to engage in some kinds of economic activity and not others. Hence social movements may be the decisive force to trigger a positive socio-economic trajectory for a region.

Some of the key concepts of Social Movement Theory are summarised in Table 5.

Table 5: Elements of Social Movement Theory

Elements	Characteristics
Mobilisation	Mobilisation is central to SMT. It is concerned with the way (how and why) social movements emerge and are able to organise action and participation, create networks, and utilise resources to advance collective (political or social) interests. The capacity for mobilisation is dependent on material (money, services, and institutional support structures) and nonmaterial resources (networks, symbols, authority, values).
Social conflict/ contentious politics	Another central element is social conflicts and/or 'contentious politics'. Conflicts can occur due to disparate interests and power structures. Indeed social movements are seen as the central actors embodying a societal conflict and revealing to the public a fundamental problem and what is at stake. Contentious politics are political struggles in which collective action is mobilise involving governments as targets, initiators of the issue or third parties. Tilly (2015) argues that 'major constraints and incentives for contentious politics are political opportunity structures', which refer to the features of a political regime e.g. its openness to new actors and the extent to which the government represses or facilitates collective claim making.
Framing and symbols	Framing processes are another important dynamic to understand the character of social movements. They are considered as 'schemata of interpretation' which refer to

	beliefs and meanings proposed by movement actors in order to inspire and legitimise their activities and campaigns. The framing process involves highlighting and strategically using specific issues, events and aspects in order to create feelings of identity and solidarity. Symbols are utilised as motivational elements.
Collective Identity	Collective identity is seen as vital element for the rise, perseverance and success of a movement. Identity is formed in a process of social conflict around the reinterpretation of norms, and involves the creation of new meanings that challenge the status quo of a social structure. It plays a key role in in boundary definition and the establishment of a 'we' against 'them'. This feeling of belonging is closely related to collective actions through which it is either reinforced or weakened.

Social movements suggest a lot of parallels to revolutions. A revolution is a rapid, forcible, durable shift in collective control over a state that includes a passage through openly contested sovereignty. Indeed revolutionary situations resemble extreme cases of social movement cycles: as the split within a polity widens, all rights and identities come to be contested, the possibility of remaining neutral disappears and the state's vulnerability becomes more visible to all parties. But a revolution can also present a positive social tipping point offer a chance for an overdue political reorganisation of a state. There are for instance many post-communist states which have narrowly escaped the danger of state failure and have embraced political and economic freedom (Grimm and Schneider, 2011). As evident, the forms and themes of revolution vary significantly with political opportunity structures, for example, a) featuring dynastic contenders where dynastic succession normally supplies new rulers, and b) taking nationalist forms where the system of rule already operates through populations that claim distinct national identities.

The concept of political opportunity structures which can constrain or enable mobilisation become central to interpretations of interaction between institutional and non-institutional actors (McCarthy & Zald, 1977; Schneiberg & Lounsbury, 2008a).

McAdam (1998) has synthesized political opportunity into the following dimensions:

- The relative openness or closure of the institutionalized political system
- The stability or instability of that broad set of elite alignments that typically under- gird a polity
- The presence or absence of elite allies
- The state's capacity and propensity for repression

For example, Kitschelt (1986) compared the nuclear power conflicts in four countries showing that the mobilization strategies and impacts of social movements can, to a significant degree, be explained by the general characteristics of domestic political opportunity structures. For example where political input structures were open and responsive to the mobilization of protest, as in Sweden and to a lesser extent in the United States, a search for new policies was triggered. Where they were closed, as in France and West Germany, governments insisted more intransigently on a

predetermined policy course. Where state capacities to implement policies were weak, as in the United States and West Germany, the nuclear protest movement had at least a chance to disrupt the policy against which it was mobilized. This means, when investigating tipping points the political environments provides indication for the transformative capacity of the system.

However one further aspect also plays an important role the "objective" reality and its social construction (Berger and Luckmann 1966). Some changes in the political opportunity structure may not have any effect on a social movement unless they are perceived as important by the movement itself. Structural availability must be filtered through a process of "cognitive liberation" in order to unleash turmoil (McAdam 1986). Mobilisation and protests requires the activists to believe that an opportunity exists, that they have the power to bring about change; and that they must blame the system for the problem. Hence it is important to consider both the structural opportunities and the cognitive processes which intervene between structure and action (Gamson and Meyer 1996, Diani 1996). This can be done by analysing the activists' understandings of available opportunities, the lenses through which they view potential opportunities for their movements (McAdam, McCarthy, and Zald 1996). Tipping points are subject to similar processes. For example the reunification in Germany was a significant tipping point in the lives of East-Germans (less so for West-Germans) and the long-term effects has been perceived very differently depending on their individual (or community) situation.

3 Framework and indicators for analysing social tipping points

Tipping points have become a key concept in research on climate change, indicating points of abrupt transition in biophysical systems as well as transformative changes in adaptation and mitigation strategies. However, the potential existence of tipping points in socio-economic systems has remained underexplored, although they are highly policy-relevant. We believe that the added value in recognising tipping points is to determine why and when a system follows one or another trajectory, and to understand what interventions in which contexts succeed in tipping a currently carbon-intensive regional economic system onto a low-carbon and still economically and socially prosperous trajectory.

Research on human-environmental tipping points in coal- and carbon-intensive regions addresses a number of pressing questions in the transition literature and beyond and provides a new research direction. In fact, the focus on the 'flip-side of transitions', including destabilization, decline, and phase-out of existing systems and regimes have become more important in the shift from carbon-intensive to low-carbon economies [17]. In the remaining part of the report, we focus on *climate policy impacts* and the challenges for affected regions and communities resulting from closing carbon-intensive industries.

This part of the report draws on sections 2 to for developing the analytical framework (context and interventions) and its application from political and governance perspective, with a particular emphasis on interventions including a list of indicators.

3.1 Framework

Building on the literature, we understand tipping points as a discontinuity in the development trajectory of a system, at which the system fundamentally changes its structure and dynamics. Simply put, a tipping point separates a state A from a state B. In contrast to biophysical understanding we do not assume that the outcomes of social tipping points are irreversible. Because the element of agency is an inherent part of social dynamics, there is always the chance that legalised institutions become illegitimate, established norms with new scientific evidence overthrown, violent conflicts may collapse back upon themselves, quickly democratized regimes may fall back into authoritarian rule, collapsed states may regain former strength and capacity, and segregated societies may find way back into societal integration and inclusion.

We have illustrated a tipping process in Figure 1 comprising four dimensions: tipping event, context, interventions and impact. The relationship is that a tipping event in a specific context triggers a socio-economic disruption, which leads to the introduction of tipping interventions. These ultimately trigger a tipping point leading to a bifurcation for a positive or negative trajectory and ultimately changing the context conditions. An “event” may or may not stand at the beginning, and triggers the

emergence of a tipping process (e.g. financial crisis, natural disaster). It can be endogenous to a system of interest or exogenous to it. We believe that to determine a tipping intervention the tipping context has to be understood.

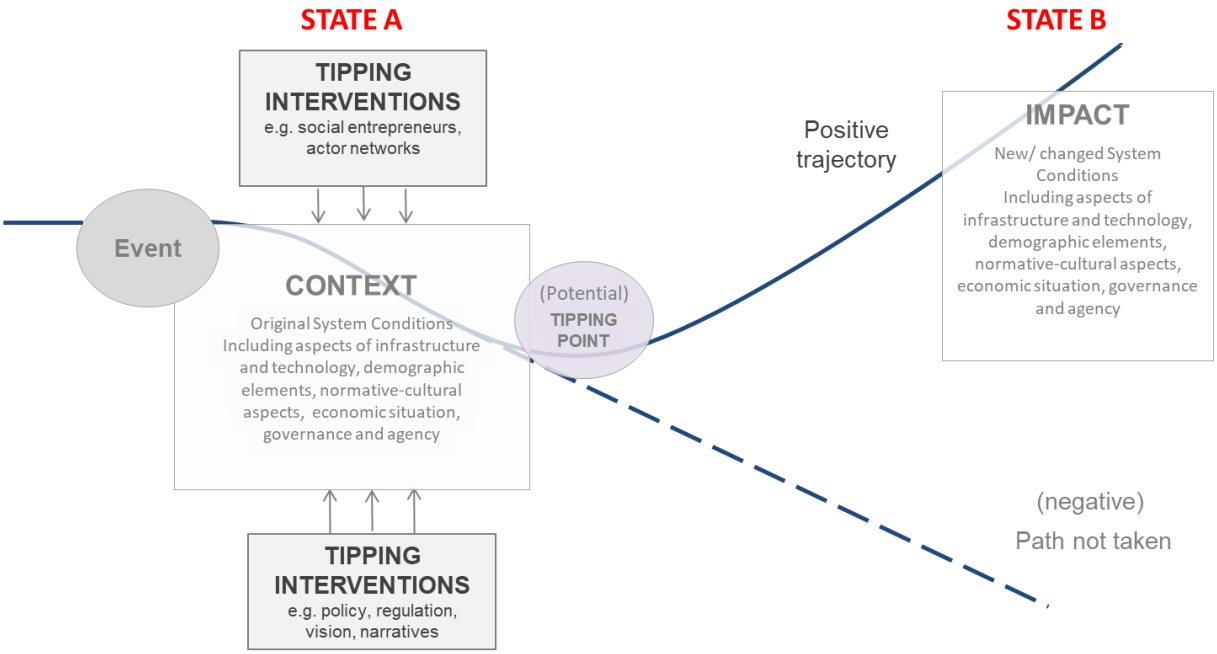


Figure 2: Illustration of our model of a social tipping point.

3.2 Tipping context

As illustrated in Figure 4 the impact of a tipping event is understood as 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 [114]. Hence explaining tipping 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 [101], [102]. Building on sociological and institutional theories (Giddens, 1984; Scott, 1995), the TEF also highlights the relevance of norms, beliefs and interpretation as well as identities of the actors involved. For example 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 pollutant, 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 which are the articulated form of plausible futures and may lead to the emergence of the desired outcomes [56]. Indeed, people use narratives not only to reflect society or to imagine a future, but also to intervene in the world and try to actively shape reality as they know it [115].

The tipping point analysis focusses on coal or carbon intensive regions. Carbon intensive refers to two areas: (i) Upstream energy extractive industry regions (that is, coal & fossil fuels extraction areas); and (ii) Downstream carbon-dependent regions, which include analyses of specific energy-intensive sectors and services such as transport, buildings, industry and service sectors particularly important in the regions chosen.

Tipping processes can rarely be linked to a single common control parameter, such as is the case with global mean temperature in climate tipping dynamics. Indeed social tipping dynamics exhibit significantly more complexity than climatic ones. Hence the analysis should start with determining the timeframe, geographical boundaries and mapping out the political, social, and economic characteristics of the selected region.

We suggest investigating the following elements comprising qualitative and quantitative indicators as presented in see Table 6 and

Table 7:

- General context e.g. demographics – e.g. who lives in the region and what is their education?
- Business context e.g. e.g. what is the local economic situation and dependencies, what are the human and social resources incl. individual income, poverty rates, GDP, skills and expertise?
- Political context - e.g. how is the region governed, who are the relevant regional actors (incl. NGO fabric existence) and what are their agendas? What's the level of social cohesion?
- Social context - e.g. how does the majority think about their region and the subject 'coal', what are dominant and emerging narratives, frames and visions?

The investigation could start with understanding the economic situation from quantitative indicators investigating the incumbent industries, key sectors and employment situation. We suggest capturing all quantitative indicators over a time span of at least 10 to 15 years in order to identify trends and changes in key indicators. However, the longer the timeframe the more likely it is to actually identify tipping points and not only context related fluctuations. As discussed above it is crucial to differentiate between "historical causes" and "constant causes". Significant population developments – migration in or out of a region – as well as an major increase or drop in employments rate can indicate either positive (as in growth of local population) or negative (as in decline, emigration of the local population with regard to certain birth cohorts and education levels) tipping points. For example the close of a major industry (e.g. coal mine) in a region is often followed by significant lay-offs, 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 regards population size, income levels (same or higher as in comparison to the national average), employment and GDP.

Another entry point is mapping the key regional stakeholders and their positions, as well as the public communication about the change(s) (event) that happen in the region. This includes understanding power dynamics between incumbent and other sectors (green sector), the political composition of government and political activities of civil society.

The political system could be investigated for the degree it is characterized by cohesion or fragmentation; that is, the degree to which one or two parties dominated the electoral arena or, conversely, the degree to which electoral competition dispersed political power. This can ultimately provide indications for the strength of policy interventions and their transformative capacity. The political regime should be also characterized e.g. showing polarizing or centrist, integrative dynamics expressed or embodied by dominant parties or party alignments that inhibited political polarization.

Furthermore, public budgets should be investigated by looking into the availability and distribution of public investments or conversely the degree of debt burden of government. This will help to determine if public investments or public investment support programmes in specific (sustainable) sectors are possible, if some support for sustainable sectors already exists and if a reallocation of budgets would be possible at all. It will also provide an indication if there is a tradition of public interventions or not, and whether the government is an active player co-creating the region towards a sustainable future.

Indicators about employees and sector distribution will tell about the region's general economic conditions and also its dependence on single industries and the monopoly status which is (often) associated with significant political powers. The production output (incl. share of exports) of selected industries (e.g. MW, tonnes of coal) in relation to national or international markets further shows the region's dependence on external market developments. The presence of a "green sector" can indicate the sustainable innovation potential, the progress of industrial change and the adaptation to the industrial change.

However quantitative indicators (only) might give a misleading picture of the region.

Narratives and frames also play an important role to understand the perception of the regional actors and their transformative capacity. For example one of the key questions for the Civil Rights movement was to figure out how to mobilize people. There were a number of possible framings for this, but the one that eventually won out was the philosophy of nonviolent protest. This framing was consistent with general Christian values and produced a positive identity for participants. It was specific leaders who developed this idea and disseminated it to others. These leaders and the framing of identities for mobilization were pivotal to the ultimate success of the movement [116].

Hence quantitative indicators should always be supplemented by a qualitative assessment. Also, WP 1 and 2 will provide more insights and input for the qualitative indicators.

The list of indicators presented below should help to identify processes that facilitate and deepen transformative change and/ or resistances to it.

Table 6: Quantitative indicators for the context pre- and post-tipping

Variable type	Variable examples	Possible questions
General context		
Demographics	Population Composition of gender Education levels Age Migration patterns Life expectancy *(only relevant over longer time frame)*	Who lives in the carbon-intensive regions (demographics, gender, minorities)? What are they doing in terms of jobs and education? What (if any) migration patterns can be observed? 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, steel)	Number of employees / share of local employment Contribution to local GDP Subsidies / subsidies relative to turnover, value-added Production output (e.g. MW, 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 much public subsidies in relation to value added do they receive?
Presence and importance of other sectors	Number of companies employing 10%, 20%, 25% of the workforce Share of public vs. private sector in Regional GDP Employment Number of employees / share of local employment Contribution to local GDP	
Presence and importance of green sectors	Number of employees / share of local employment Number of companies active in the regions Contribution to local GDP Subsidies / subsidies relative to turnover, 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 much public subsidies in relation to value added do

Variable type	Variable examples	Possible questions
		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 or carbon intensive industries? What role does COAL or carbon intensive industries play in legitimising their power?
Public opinion on 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 own participation in transformation processes?
Public budgets	Funding for different levels/ ministries, branches of government (total or spending per capita) • 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 public investments or public investment support programmes possible? Do public investments or public investment support programmes already exist, and can the region tap into them? Are the public budgets balanced? Is there room for additional spending? Are existing investments or other structural change programmes available? 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, advocacy)	Are citizens engaged in improving the environment in their community, region, country or in general? What is their position on COAL or carbon intensive industries? What is their position and activities regarding the specific activity that closed?

Variable type	Variable examples	Possible questions
NGOs membership	Number of members (funding or active) in climate and environmental NGOs and other associates (as per indicator above)	What is the membership size of these NGOs? How many people actively engage or are funding members? What political influence do these NGOs have?
Mining and Steel/ Energy Unions	Number of members on • National • Regional • Local level	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 (or carbon intensive industries) provide for regional cultural and sport events/ activities? 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 (Facebook, Instagram) • Media coverage of COAL (direction) • Number of positive (pro-closing, pro-transition) and negative (anti-closing, anti-transition) newspaper articles • Number of positive/negative public service TV (news) reports • Number of positive/negative online newspaper articles or social media (Facebook, Instagram)	How often does the COAL (or carbon intensive industries) appear in the local news (newspapers, online news, social media)?

Table 7: Qualitative indicators for the context pre- and post-tipping

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, 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, • political media articles and social media? How do these frames legitimise/ delegitimise COAL or carbon intensive industries as regional economic resource? What do people associate with COAL or carbon intensive industries?
Self-image	Self-perception: • What do people think in which way 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 we do, what can we not do? What is our place in the world?
External perception	External perception: • What do people outside of the affected region think of the region, its people and what happens there? • Who are ***they*?**	Who are the people in the region? What do they do? What can they do, what can they not 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 & industry associations • civil society organisations • NGOs • Unions	What is COAL (or carbon intensive industries)? Why is COAL (or carbon intensive industries) important? What problems are caused by COAL or carbon intensive industries? Is COAL (or carbon intensive industries), in balance, good or bad?

Variable type	Variable examples	Possible questions
	• General national discourse • National media	
Perceptions about COAL beyond the region (e.g. in the capital)	Narratives used by actors in regard to COAL (or carbon intensive industries): • national actors: government & parliament • industry & industry associations • Other industry • civil society organisations • NGOs/ Unions • General national discourse • National media	What is "COAL" (or carbon intensive industries)? Why is COAL (or carbon intensive industries) important? What problems are caused by COAL (or carbon intensive industries)? Is COAL (or carbon intensive industries), in balance, good or bad?
Perceptions about the future		
Internal visions	Narrative visions put forth (dominant, minority) by local actors	Who do we want to become? What do we want our region, 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 (dominant, minority) by national, European actors	Who do we want the region to become? What do we want that this region, community should develop into? What will they do in the future? What should be their place in the world?

3.3 Tipping interventions

The most important characteristic differentiating social from biophysical (climate and ecological) tipping processes is the presence of human agency [30]. Human agency is understood as a conscious and cognitive process including foresight, planning, normative-principled and strategic thinking, which allow human beings to purposefully affect their environment on multiple temporal and spatial scales (ibid). Deliberate interventions capture this notion of human agency and represent a key elements in a tipping point process either leading to positive or negative trajectories.

We understand social tipping interventions as deliberate and purposeful actions from individual or collective public (e.g. government, civil society) or private (e.g. industry, businesses) actors to intervene in a system to accelerate, avoid or facilitate (manage/ coordinate) a tipping point process in a social system in a delineated timeframe (e.g. 10 years). For example the introduction of the German Renewable Energy Act (EEG) – an in itself small, national policy intervention – formed a market for renewable power in Germany, which led to substantial deployment that triggered very strong learning effects, and the decreasing costs made renewables attractive also to other countries, until renewables entered a virtuous cycle of self-reinforcing market growth and global cost improvements [117], [118].

Interventions can constitute a range of aligned or nonaligned measures initiated in parallel or temporal sequence directed towards a geographical area, a population group or an industry (segment). Impacts of TP interventions can be intended and bring the desired outcomes (e.g. close of an industry maintain stable employment) or they can be unintended and bring adverse outcomes (e.g. close of an industry and complete socio-economic decline of a region). Another example for unintended yet positive impact is a recent example from Chile, where a minimal increase in the public transport fare created massive country wide protests with 26 death, churches ablaze and hundreds arrested. Chileans voiced their anger over inequality and injustice and pushed for deep structural changes demanding for a new constitution with more rights and better social protections. On the 25th October 2020 a public ballot was held reaching an overwhelming majority in support of rewriting Chile's constitution, which dates to the military rule of Gen Augusto Pinochet. This points to the fact that also societal inequalities and questions of energy justice are important considerations in the investigation of abrupt societal change dynamics [119]–[121].

Whether an intervention is smaller or larger does not necessarily predict their positive tipping potential or the scale of change. In fact, certain groups do have the ability to intentionally create disruptions through acts of resistance and protest, or influencing local perception even without an abundance of resources. Hence they create the opportunity space for action and interaction, and consequently the conditions for transformability [49], [122], [123]. On the contrary, large policy interventions (e.g. public funding) might not have (other than intended) systemic impact on national level. Though for individual communities they could trigger a tipping point into a positive trajectory. For example the establishment of a new large factory for electric vehicles in Brandenburg largely supported by state and national government will provide 12.000 new jobs in the region though its impact for a

sustainable transport sector is limited. In fact, a radical transformation of the mobility sector requires us to move away from car focused individual transport, to shorter commutes and sustainable public transport.

Another example: Spain is in the process of phasing out its entire coal production after a landmark deal was struck between government and unions of €250m in 2018 which will be invested in mining regions over the next decade [124], [125]. The phase out already started in the 2000s. Though, the close 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 e.g. early retirements, local infrastructure development have been less effective [125], [126].

Otto et al. (2020) differentiate into small and big interventions leading to small (such as changes in individual life trajectories) or large effects (broader system changes) (see Table 8).

Table 8: Illustrative examples of intervention-and-effect relationships

Intervention type	Examples of small effect	Examples of large effect
Small intervention	Incremental change e.g. for emission reduction through local climate policy Unionised deals e.g. with mining companies for workers compensation, further training and ensuring workers are not neglected in the phase out process e.g. Spanish transition deal.	Tipping effect for e.g. cost reduction of renewable energy from the German EEG so that PV has become 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 [6] Potentially: Coal Commission in Germany, 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 e.g. 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

Adapted from Otto et al. 2020.

Further, the intensity of an intervention which is understood as the amount of single measures and the length of the intervention can also constitute a decisive category. In fact, "the more the better" might not yield desired outcomes, yet instead purposeful interventions will be more efficient and effective for reaching a positive

tipping point. Of course, large interventions are easier to identify, so are short and punctuated interventions. However interventions could also have longer timeframes, yet, then the actual tipping points might be triggered by a combination or alignment of additional factors. Consequently delineating the scale and geographical boundaries of the research subject are crucial.

The closing of a dominant industry is often discussed as a major economic disaster for the affected region, and sometimes they are. However, such major societal events are somewhat Newtonian in that they also trigger opposite reactions: policy intervenes, businesses adapt their activities, and societal actors take new initiatives to shape the new situation. Such interventions can be very diverse, but they all go in the same direction and all aim for the same thing: new economic and social prosperity for the region, the companies and people there.

Similar to the context indicators there are three main focus areas, these will be discussed in turn and Table 9:

- Policy interventions;
- Business interventions;
- Social interventions.

3.3.1 Policy interventions

Typically, when a key industry closes, policy at different levels, both national and regional/local, intervenes to expand and diversify economic activity in the region, thereby creating new jobs. Such measures typically include economic policies, ranging from direct public investment (e.g. in infrastructure, to improve the mobility of people and goods) to investment support (e.g. soft loans for companies locating actives in the regions) and direct subsidies and tax exemptions.

Generally, a main aim of policy interventions is to keep people employed so that they stay in the region. If measures to attract new businesses are insufficient, such measures may include commuting solutions, for example supporting house ownership near (new) rail links to nearby cities; there are many examples of such "sleeping cities" arising in the still growing economic gravity fields of the big cities. This also includes funding for labour-intensive projects (e.g. site remediation and plant decommissioning) and infrastructure upgrades. Finally, and especially for remote regions, measures to support de-populating a region are conceivable, including support for moving to another city, to avoid too high unemployment rates and social problems.

Professional retraining and capacity building is an important element to prepare the local community for the changes in the local job market and create the skills needed for the envisioned transition. Establishing new universities or relocating research institutes can help to keep the young people in the region and potentially attract further qualified personal to the region. In this regard, 'smart specialisation' (extending the capabilities of existing industries and workers) is a new policy strategy. Measures from industry can also include retraining, reskilling, and supporting workers to migrate to other stations or into new industries.

Policy interventions can also creating better framework conditions for spin-offs and start-ups. Large scale intervention often include a particular focus on innovations and

the establishment of research institutes (R&D), transport technology and digital infrastructure. This also includes the development of 'clusters' (inter-linkages with related industries and educational institutions) and fostering the establishment of new industries.

3.3.2 Industry/ business interventions

Industry and businesses play a critical role, both as the actors carrying out the economic changes triggered by policy interventions (e.g. responding to economic incentives to invest in the region), and as potential initiators of interventions.

The industry that closed naturally has limited options: if the coal mine is closed, it cannot offer jobs in the coal mine. Nevertheless, the affected companies often decommission their activities over time, and sometimes in "socially balanced" manner [127], [128]. This holds simple measures such as a timeline for lay-offs, and not only a final end-date. Often, industries offer re-training programs, either to move workers to other sites within the same mother company, or – then typically together with policy measures – retrain workers to prepare them for different tasks in other companies of sectors.

A critical role falls on the other companies in the region, potential new companies forming, and on business that may expand into the region: they are the primary target of many policy interventions, and the places in which new jobs are to arise.

Interventions by local social (institutional) or technical entrepreneurs can play a decisive role in transforming their region towards sustainable futures. The common association is that entrepreneurs are individuals identifying a market opportunity for a technology and developing a viable business model to exploit it. This may include clean energy technologies or other e.g. digital solutions. "Social entrepreneurship" captures the entire process through which "social entrepreneurs" create and develop organizations - "social enterprises" with the purpose to create and sustain social value. Solutions by social entrepreneurs include socially innovative initiatives in a spectrum from for-profit to voluntary organizations often with the aim to enhance social wealth. Innovation can be pursued through new organizational models and processes, through new products and services, or through new thinking about, and framing of, societal challenges. Several social entrepreneurship initiatives combine these different ways of innovating. Mazzucato (2018) also emphasizes the entrepreneurial and lead investor role of public actors, willing and able to take on extreme risks, independent of the business cycle [129]. Indeed this has been illustrated particular in the case of clean technology and the role of public finance (e.g. state investment banks) [129]–[131].

3.3.3 Civil society and citizen interventions

Citizens and societal organisations, from the local football club to Rotary, are important for the social fabric of a region. Although their economic means are often limited compared to national and regional governments, they are important for the non-economic aspects of the quality of life in a locality. The number and quality of social contacts are one of the strongest predictors of a person's satisfaction with her or his life, often less than the income [132]. Indeed, the network of clubs and

cultural institutions as in opportunities to engage with one's community are often among the first things to be affected when a regions "goes bad", adding social isolation to a difficult economic situation. The current health crisis demonstrates this very dramatically in many countries around the world [133].

Social organisations may also actively engage to improve the situation as the key industry closes. For example, they may initiate, or participate in, processes of "redefining" the region: who do *we* want to be, what is *our* place in the world? They may also initiate or participate in campaigns to inform about new.

The work of civil society organisations is particular important since they contribute to social capital development which is independently of the state or large corporations (e.g. in terms of the organisations, structures and social relations that people build up themselves). Putnam (1995) suggests that it provides an important function in terms of strengthening community fabric. High social capital, in the form of social trust and associational networks, is associated in the literature with a wide range of desirable policy outcomes (Halpern, 2001). These include e.g. better health (Wilkinson, 1996), improved longevity (Putnam, 2000), better educational achievement (Coleman, 1988) and greater levels of income equality (Wilkinson 1996, Kawachi et al. 1997).

Table 9: Intervention indicators

Intervention type	Intervention example	Intended effect
Policy interventions		
Public investments	Build new infrastructure (rail, road)	Improve transport of goods and people to/from the region; allow 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 investments in new economic activity, jobs creation
Subsidies	Subsidies or tax exemptions for companies present	Keep companies in the region, maintain employment
	Subsidies or tax exemptions for companies expanding in or to the region	Attract further companies to the region, create further jobs in already existing businesses
Education	Fund university, fund new university program	Attract young, qualified students to the region; create the skills needed for the envisioned transition
	Found or move R&D institute	Attract skilled R&D people to the region, trigger regional spin-offs

Deliberation processes	Local engagement process	Build new vision for region
Population management	Support for families moving away	Reduce unemployment in affected region, create new opportunities for citizens and other regions
	Lower property tax, soft loans for buying property in regions	Keep population in the region by supporting house ownership
Local interventions	Fund local initiatives and associations	Support local social capital
Business/industry interventions		
Investments	Expand existing operations	Expand local value creation, new jobs
	Found new operations	Expand local value creation, new jobs
	Relocate from other region	
Education	Re-train existing employees	Enhance skills, direct skills towards what is needed in future (keep existing employees employed)
	Train new employees	Teach new employees necessary skills for future operations, scope of company
	Work with government to design new education programs, university foci	Teach new employees necessary skills for future operations, scope of company and the governmental vision for the region
Entrepreneur initiatives	Start-ups and technology and business innovation	Establish a flexible and supportive business environment for start-ups and other entrepreneurial innovations
Societal interventions		
Citizen initiatives	Network support for businesses and other stakeholders	Create movement of orchestrated policy, business and civil society actions to achieve new vision for the region
	Bottom-up visionary discussion processes	Build new vision for region, build social trust and associational networks
Education	Information campaigns about environmental awareness and health	Create awareness, educate and build local social capacity

Social networks	Collective action	Support local initiatives and NGOs in order to create or maintain social capital

3.4 Impact: was a tipping point triggered?

Similar to critical moments or junctures, tipping points can usually only be identified retrospectively in reference to the specific historical legacy or systemic change [62], [63], [76]. Tipping points produce specific development paths or trajectories and their impact is associated with a fundamental and qualitative change in the context conditions of a system. A change in the structural trends and dynamic of a system can be a measurement for the impact after a tipping point. This involves for example the development of a region in regard to e.g. economic growth and equality, employment, migration etc.. In fact it has been suggested that there are positive and negative tipping points [29], [56], [78] allowing for qualitatively different developments and impacts over time.

While we are looking for positive tipping points, their impacts should constitute qualitative improvement in the socioeconomic situation of individual or community life which includes e.g. higher (or not reduced) income, better (or not impaired) health, education and local economic development.

Hence, identifying a tipping point requires the investigation of the suggested context indicators over a certain period of time and look for significant changes in their development.

However there are challenges in identifying the impacts of tipping points:

- First, 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 receive for longer-term developments.
- Second, systemic changes are subject to individual and collective perception and influence the labelling of a certain tipping point as positive or negative. For example the reunification in Germany was a significant tipping point in the lives of East Germans (less so for West Germans) and the long-term effects has been perceived very differently depending on their individual (or community) situation. In addition, data about the different perceptions might be more difficult to obtain.
- Third, the importance of a tipping point may be visible only in the long term, which will have a direct impact on selecting a timeframe of analysis.
- Fourth, tipping points are not necessarily "points" but can also be stretches of time during which sequences of events unfold. The complexity of social systems can make it challenging to identify causality and datasets for measurement.

4 Discussion

As climate protection policies progress, an increasing number of regions will face economic difficulties because key industries are forced to close. Hence, the question of how to maintain or even increase economic and social prosperity in these currently coal- or carbon-intensive regions is already important and will gain importance in the coming decade. Across Europe, there is much experience with structural change: industries have closed or moved to other countries, mines have been depleted or become unprofitable. What is new today is the trigger for such processes: if they were economic in the past, they are today also (climate) political. Many of the regions affected by such processes in the past have today bounced back and are prosperous centres. What is lacking is a systematic knowledge of how that worked: what did political, economic and social actors do, and which interventions worked in which contexts – and which did not work?

Today, governments spend vast sums trying to "save" regions in economic decline. Yet, the research for *how to achieve* the intended social tipping points in places negatively affected by climate policies is new research field. A wealth of knowledge about tipping points has already arisen in other research fields, especially in climate science and environmental research, and there is a rich political literature on structural and societal change. While these help to shed light on a number of questions for the social realm, they need to be combined in inter and transdisciplinary research to create a comprehensive theoretical foundation for social tipping points and the role of interventions; in addition, empirical work is needed to better understand when social tipping points emerge, how particular interventions may (or may not) trigger tipping in specific contexts is. The rich economic history of Europe, both distant and recent, offers plenty of opportunity for such study, and we will take first steps in this direction in TIPPING$^+$, based on this and further reports from other disciplinary perspectives. Indeed answering the crucial question what interventions support tipping processes in which contexts which will require interdisciplinary integration of insights from many disciplines, including political science and public policy analysis, but also anthropology, psychology and economics.

There has been much research on various aspects of tipping points over the last two decades. However, the tipping point concept has rarely been applied of tested in socio-technical and socio-economic transformations research. Hence, new promising future research directions emerge for thinking about policy processes and possible intervention options in coal- and carbon-intensive regions. To provide some further direction, case studies researchers, in TIPPING$^+$ or elsewhere, may want to explore and test some of the following hypothesis for how to induce a positive tipping point in specific geographic, social, political or economic contexts:

- Rural regions will most benefit from an expansion of public transport and other infrastructure developments which will be crucial interventions to ensure connectivity within the region and access to urban centres important to provide new job opportunities.
- The stronger a region identifies with the industry that will close (e.g. mining), earlier and more intense community interventions are necessary.

- In a region with older population, interventions have to provide economic perspectives for young people and in particular women to avoid emigration away from the region.
- In a community with a preposition for knowledge based economy, policy interventions to diversify the local labour market will be adopted faster.
- In regions with many local clubs and associations policy support should ensure that their initiatives are maintained and further encouraged in order to foster a social capital building, incl. positive local identity through collective action.
- The establishment of specialised businesses can be more successful if the region holds a university that can adapt their program to the new needs.

The present report is to be understood in this context, as a first step towards a deeper understanding of social tipping points and as a suggestion for indicators to be used in empirical case study analysis. The indicators presented here will be consolidated with the indicators from further Work Packages of the TIPPING$^+$ project and tested in selected cases. Following this, we will update the set of indicators based on the experiences from these case studies, before they are applied to a larger set of case studies in various Work Packages of TIPPING$^+$.

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