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## Regions in industrial transitions: exploring the uneven geographies of vulnerability, preparedness and responsiveness

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# Regions in industrial transitions: exploring the uneven geographies of vulnerability, preparedness and responsiveness

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## Abstract:

This article focuses on regions in industrial transitions (RITs) in the context of climate change mitigation and their varying paths towards sustainability, drawing on rich data from 11 regions in 9 countries in the Danube area in Europe. Inspired by recent work on green regional vulnerability, challenge-oriented regional innovation systems and transformative resilience, the article conceptualizes regional industrial transition pathways as the outcome of a complex interplay between distinct geographies of (1) vulnerability to, (2) preparedness for, and (3) responsiveness to transition pressures. Empirically, the article employs a mixed-method approach, combining quantitative analyses of regional structural conditions (focusing on vulnerability and preparedness) with qualitative investigations of agency of regional and non-regional actors (focusing on responsiveness). In doing so, the article unravels diverse pathways that regions adopt to navigate industrial transitions. We contend that these insights hold important implications for the design of tailor-made regional industrial transition strategies.

## Keywords:

Regions in industrial transitions, vulnerability, preparedness, responsiveness, transformative resilience

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# 1 Introduction

The past years have witnessed significant changes in the contextual conditions for regional development. The urgency surrounding issues like climate change, biodiversity loss and other environmental problems has been steadily escalating. In response to these challenges, ambitious environmental goals and programs such as the Paris Climate Agreement (United Nations Framework Convention on Climate Change (UNFCCC), 2016) and the European Green Deal (European Commission, 2019) have been implemented to foster more climate-friendly economic activities and green transitions.

This creates significant socio-economic restructuring pressures, which are, however, unevenly distributed across space. Some places are clearly more affected than others, reflecting a distinct “geography of problems” (McCann and Soete, 2020). This article concentrates on places that feature particularly pronounced transformation needs in light of climate change mitigation efforts. These regions are referred to as **regions in industrial transitions (RITs)** (OECD, 2023). RITs show a strong specialization in emission-intensive sectors such as mining, steel, cement, paper, and aluminum. These industries are confronted with enormous decarbonization pressures that will lead either to deep-rooted transformation processes, or, as in the exemplary case of coal mining, to their deliberate phase out (While and Eadson, 2022). Given the strong spatial concentration of these industrial activities in specific regions (Rodríguez-Pose and Bartalucci, 2023; OECD, 2023), the necessity for deep decarbonization poses a significant disruption risk, endangering RITs of becoming the next victims of spatially uneven development and, potentially, ‘left-behind’ places (Martin et al., 2022; Rodríguez-Pose and Bartalucci, 2023). This highlights the urgent need for comprehensive place-based transition strategies and policies.

Many discussions focus on explicating which places are particularly exposed to transitions and the potential economic, social and political problems associated with them (OECD, 2023; Rodríguez-Pose and Bartalucci, 2023). However, it is equally important to understand what context-specific options RITs have to address transition challenges, how potential solutions are negotiated and developed, and how this translates into different **pathways of regional industrial transitions**.

This article has three aims. First, we seek to provide a better understanding of the uneven geography of **vulnerability** to climate change mitigation efforts. We argue that regional vulnerability is determined by the industrial structures inherited from the past. In this way, RITs can be identified. However, while understanding the exposure of regions to transition pressures is crucial, it only tells part of the story. Equally important is how well-endowed regions are with assets to cope with the transition imperative. Therefore, the second aim of this article is to cast light on the geography of **‘preparedness’**. In this article, we contend that preparedness is related to economic and innovation system structures and capabilities, the potential and capacity to phase in new green activities, and previous successes in decarbonization.

However, recent contributions have clearly shown that structural perspectives alone are insufficient to explain regional economic development and sustainability transitions<sup>1</sup> processes (see, for instance, Isaksen et al., 2019; Grillitsch and Sotarauta, 2020). While vulnerability and preparedness measures can help to identify RITs, and unravel potential assets transition processes can draw upon, they tell us little about what we call regional ‘**responsiveness**’, that is, ongoing agentic processes ‘on the ground’. Therefore, adopting an agency perspective, the third aim of this article is to examine the role of regional as well as non-regional actors and their strategies, interventions and struggles to influence regional transition processes, thereby contributing to a better understanding of the geography of responsiveness.

Taken together, this article seeks to uncover the uneven geographies of vulnerability, preparedness, and responsiveness to provide novel insights into regional industrial transition processes in response to the climate crisis. In doing so, the article is inspired by work on regional economic resilience, which has provided insights into the impacts of shocks and crises on regional economic development trajectories (Martin and Sunley, 2020).

Empirically, the article draws on rich quantitative datasets and statistical analyses as well as intensive document analyses and semi-structured expert interviews to examine transitions in 11 regions situated in 9 different countries in the Danube macro area in Europe. Despite their significant diversity, these regions share the common challenge of confronting the imperative of profound industrial transitions. This shared challenge, along with the rich empirical data available, enables a comprehensive and comparative study of regional vulnerability, preparedness and responsiveness.

## **2 Conceptual considerations**

This section lays the conceptual foundations for examining the geographies of (1) vulnerability, (2) preparedness and (3) responsiveness. We discuss each notion individually before presenting a framework that illustrates the interconnections between these dimensions.

### **2.1 Vulnerability: Exposure of regions to the transition imperative**

Vulnerability understood as the propensity of firms, industries and regions to different types of shocks and crises, is a key dimension of regional economic resilience (RER) models (Martin and Sunley, 2020). In this subsection, we explore the question of how vulnerable regions are to (the negative impacts of) industrial transitions. Recent work by Rodríguez-Pose and Bartalucci (2023) has shown that regions with a strong specialization in “dirty” industries, agriculture, and tourism, are particularly exposed to the adverse repercussions of climate change mitigation policies. Other studies have focused on the role of specific sectors like coal mining (Alves Dias et al., 2018) or energy production (Carley et al., 2018) in examining regional vulnerability to decarbonization efforts.

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<sup>1</sup> We understand ‘sustainability transitions’ as an overarching term capturing a wide array of processes towards more sustainable ways in different domains (mobility, energy, ...). ‘Industrial transitions’ are considered here a subtype that focuses specifically on transition processes in the industrial domain. This distinction, however, should not neglect the interrelations that exist between different domains (e.g., energy and industry) and that underpin sustainability transitions.

Energy-intensive and high-carbon industries are central to discussions about the transition imperative necessitated by climate protection policies. McDowall et al. (2023, p. 4) highlight that vulnerability is “*understood as a function of the exposure of a region to likely job losses in carbon-intensive industries*” (p. 4). This perspective is corroborated by findings that indicate that regions with high per-capita emissions and significant employment in energy-intensive industrial sectors are at greater risk and face more challenges during industrial transitions (OECD, 2023).

High vulnerability to industrial transitions holds disruptive potential and can negatively impact the socioeconomic conditions of regions. When unsustainable industrial activities are deliberately downsized and dismantled, regions with unsustainable industrial structures may face economic decline and job losses (Fiorentino et al., 2024). This economic downturn can lead to social and political unrest among inhabitants, as recent debates on “green discontent” and resistance to the green transition show (Rodríguez-Pose and Bartalucci, 2023).

Drawing on these insights, this article examines the concept of “vulnerability” from an industrial transition perspective. It suggests that regions with historically-grown specializations in energy- and emission-intensive industrial activities face significant social, economic and political repercussions due to mitigation policies responding to the climate crisis. Accordingly, a high degree of regional vulnerability indicates an urgent need for comprehensive and just strategies for regional industrial transitions towards sustainability (McCann and Soete, 2020; OECD, 2023; Tripl et al., 2024).

## **2.2 Preparedness: Regional potentials and capacities to cope with the transition imperative**

Regions have varying capacities to respond to and cope with transition pressures (McCann and Soete, 2020; Rodríguez-Pose and Bartalucci, 2023). In this article, we employ the notion of “preparedness” to uncover such capacities. The literature on RER is helpful in this regard. It directs attention to the ability of regional economies to withstand, reconfigure and transform in response to shock events (Boschma, 2015; Martin et al., 2016).

Over the past years, different variants of RER (including bouncing back and bouncing forward perspectives; see, for instance, Martin and Sunley, 2020) have been discussed. In this article, we adopt the concept of transformative resilience, which is defined as the “*capacity of places to leverage [...] a crisis to pressing economic, ecological and social problems and to embark on a more sustainable development trajectory [...]*” (Tripl et al., 2024, p. 105). This perspective offers an entry point for understanding how disruptions could lead to an alignment of regional development trajectories with longer-term sustainability goals (‘bouncing beyond’). In other words, work on transformative resilience examines the conditions under which shocks may catalyze a reorientation or even transformation of regional socio-economic structures and could enhance the challenge-orientation of innovation systems, which is considered vital for transitions (Isaksen et al., 2022).

We contend that this perspective, through its links to the concept of challenge-oriented regional innovation systems (CORIS) (Tödting et al., 2022), can contribute to a reassessment of the

regional assets and capacities needed to effectively address territorial sustainability challenges (Tripl, 2023). In line with the CORIS framework, our approach to assessing the preparedness of regions for industrial transitions incorporates a wide set of assets beyond the conventional scope of RIS scholarship and explicitly considers the degree of reconfiguration of structures. We focus on the following “pillars” of preparedness:

- First, innovation capacities constitute an important part of a region’s structural preparedness. Many studies have underscored the pivotal role of the regional knowledge base in facilitating sustainability transitions (Grillitsch and Hansen, 2019; Tripl et al., 2020). However, following the CORIS concept, it is important to not only consider the general innovation performance, but also the degree to which RIS knowledge generating structures have been realigned with economic, social and environmental goals (Isaksen et al., 2022).
- Second, institutional framework conditions, encompassing both formal and informal institutions, play a crucial role in shaping transition processes (Flanagan et al., 2023). Formal institutions are instrumental in providing structures, reliability and rules in innovation systems and are therefore important in influencing interaction and collaboration among actors (Hölscher et al., 2019). Informal institutions, such as practices, conventions, and norms, can significantly drive or impede transition processes, depending on their orientation (Flanagan et al., 2023). For instance, widespread doubts about climate change or support for populist parties may curtail a region’s preparedness (Rodríguez-Pose and Bartalucci, 2023).
- Third, transitions processes might require new and sometimes overlooked assets and demand new ways of doing things. Therefore, the potential to phase in new activities is an important dimension of regional structural preparedness. In this regard, natural resource endowments, such as renewable energy sources, might signify promising avenues for industrial transitions. Moreover, future diversification efforts into new green fields could build on ongoing or past sustainability-related economic activities.
- Fourth, it is important to consider previous successes in shifting to more sustainable forms of regional development. Therefore, the progress in phasing out unsustainable practices can be regarded as one dimension of structural preparedness and a proxy for successful reconfiguration of RIS structures (Suedekum and Rademacher, 2024).

In summary, we embrace the CORIS approach and propose understanding regional “preparedness” as being contingent upon regional assets, resources and capabilities industrial transitions can build upon. Higher levels of preparedness indicate a broader and deeper range of possible regional transition pathways and reflect opportunities for sustainable shifts.

### **2.3 Responsiveness: agentic processes in response to the transition imperative**

Structural perspectives provide crucial insights into the vulnerability and preparedness of regions. However, these alone cannot sufficiently explain pathways of transformative change, or their absence, in response to the intensifying transition pressures. Various scholars (Grillitsch and Sotarauta, 2020; Sotarauta et al., 2020; Tripl et al., 2020; Baumgartinger-Seiringer, 2022) have argued for incorporating an **agency perspective**, directing attention to the question of how actors address sustainability challenges.

Previous work in economic geography and related disciplines has differentiated between various forms of agency, including change, reproductive, and maintenance agency (Bækkelund, 2021; Baumgartinger-Seiringer, 2022). It has also been shown that agency can be oriented towards exerting influence at the organizational or the wider regional system-level (Isaksen et al., 2019; Blažek et al., 2023).

In this article, we draw on the concept of transformative resilience to unravel various agentic responses to sustainability imperatives through which actors confront and adapt to challenges such as transition pressures in RITs. Following the framework proposed by Tripl et al. (2024), we examine the role of agentic processes in four core processes (see also, Hölscher et al., 2019).

- Firstly, the identification of both, territorial challenges and assets to address regional problems and needs, is essentially shaped by manifold actors and their agencies. Different regional and non-regional actors might have very different perceptions of territorial challenges, their sources and severity as well as of what assets that should be mobilized to tackle them.
- Secondly, agency also matters in the search for and diffusion of innovative solutions. The question of how various actors drive or impede this process through change and maintenance agency is vital for understanding regional responsiveness.
- Thirdly, unlocking unsustainable development paths and structures ('exnovation') is crucial for transitions. It often requires significant shifts in policy, investment, and societal norms, confronting entrenched interests that may resist change (Heyen et al., 2017).
- Fourthly, the success of orchestrating the interests, visions, priorities, and activities of local and non-local actors is vital. This process involves managing conflicts, fostering collaborations, and negotiating compromises between diverse stakeholders.

Importantly, these four processes must be understood in their multi-scalar complexity, recognizing that they are shaped by both regional actions and non-regional economic and political actors and influences (Martin et al., 2022). Exnovation, for instance, often has its origin on higher governance levels, but will be mediated by distinct spatial contexts and translated differently into development pathways at the regional level.

The conceptual considerations outlined above help to broaden our understanding of regional transitions. By incorporating an agency perspective, we are able to cast light on how different actors, based on various forms of agency, interact with structural conditions (and the vulnerabilities and preparedness residing within structures), thereby driving or impeding transition processes (Tripl et al., 2020). This allows to uncover the inclusion, exclusion, struggles, controversies, inconsistencies and competition between different (regional and non-regional) actors and their goals that underpin industrial transitions.

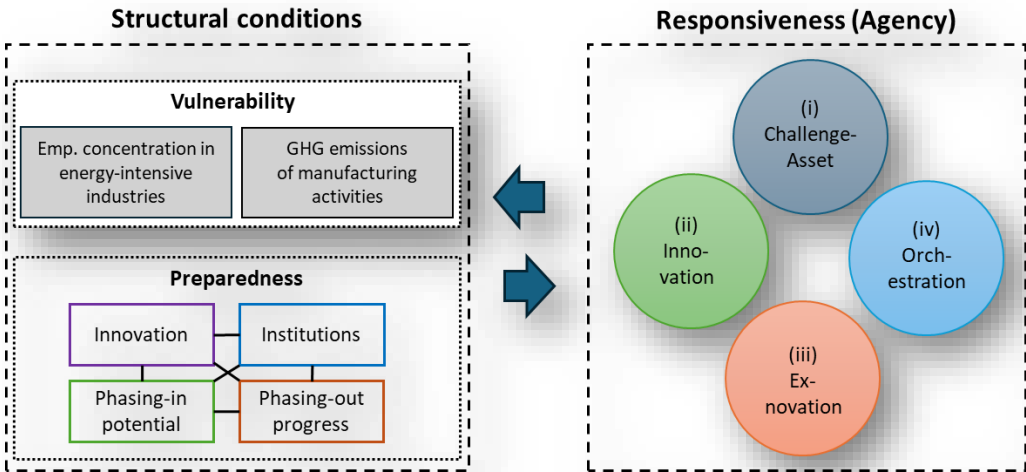
#### **2.4 Regional industrial transition pathways as outcomes of an interplay between vulnerability, preparedness and responsiveness**

The conceptual considerations outlined above help to grasp the uneven geographies of vulnerability, preparedness and responsiveness. In this subsection, we elucidate the

interconnections between these notions and propose a conceptual framework that allows us to distinguish four ideal-type regional industrial transition pathways in RITs.

Vulnerability and preparedness are “residing” within the economic and innovation system structures of regions, but also reflect endowments of natural resources (renewable energy potential). Responsiveness, in contrast, is the outcome of agency of both regional and non-regional actors. Structure and agency stand in a continual, reciprocal relationship (Grillitsch and Sotarauta, 2020; see also Giddens, 1984). Structures are mediating agency, while agency is oriented towards molding structures in particular ways. Accordingly, agents are confronted with and continuously make sense of regional structural conditions. Given the article’s focus on RITs, we emphasize specific structures here, that is, varying levels of vulnerability measured through energy and emission intensity of regions’ industrial fabric and different assets to implement transition processes, subsumed under the term ‘preparedness’. Actors, then, act upon these conditions. We conceptualize these agentic processes through the four core processes proposed by Trippl et al. (2024). Thereby, actors shape structures in specific ways, for instance by exploiting existing assets, reducing emissions and, hence, the vulnerability of regions (Figure 1). We contend that it is this interplay that explains the uneven unfolding of regional industrial transitions.

**Figure 1: Conceptual framework: connecting vulnerability, preparedness, responsiveness**



Drawing on this understanding and focusing specifically on RITs (i.e. regions that are by definition characterized by a high degree of transition vulnerability), one can distinguish conceptually between four ideal-type regional industrial transition pathways depending on different configurations of preparedness and responsiveness (Table 1).

RITs that combine high preparedness with high responsiveness are considered to be on a *pioneering* transition pathway. These regions are well equipped with assets to implement necessary transition processes. Regional and extra-regional actors have started to actively engage with these favorable structures and demonstrate ambition in implementing more sustainable practices. Arguably, these RITs hold most promise of transitioning effectively.



RITs characterized by high preparedness but low responsiveness are on a *complacent* transition pathway. Despite having promising assets to support industrial transitions, regional and extra-regional actors have yet to exploit these favorable structures, possibly due to active resistance and maintenance agency (Steinböck and Tripl, 2023). Accordingly, these RITs have not fully unlocked their latent potential.

RITs that exhibit high vulnerability along with low preparedness but high responsiveness are considered to be on an *overreaching* transition pathway. Despite having rather unfavorable structures, these places show a high level of engagement to respond to transition imperatives. Accordingly, in these RITs potential lags behind ambition.

RITs featuring both low preparedness and low responsiveness are on a *stagnant* transition pathway. These regions face significant challenges due to their lack of suitable assets and active engagement in transition processes. Arguably, these RITs hold least promise of transitioning effectively.

**Table 1: Regional transition pathway typology in regions with strong transition needs**

Regional structural conditions		Agentic processes	Resulting transition pathway
Vulnerability (high by definition)	Preparedness	Responsiveness	
high	high	high	<b>Pioneering transition pathway</b>
high	high	low	<b>Complacent transition pathway</b>
high	low	high	<b>Overreaching transition pathway</b>
high	low	low	<b>Stagnant transition pathway</b>

In the empirical part of this article, we apply this conceptual understanding to our analyses of RITs in the Danube area.

### 3 Data and methodology

This article draws on the findings from the Horizon Europe project (project name, anonymized for peer-review) (2022-2024), which investigated regional sustainability transitions in 11 regions across the Danube area (Table 2). Sampling of case study regions was based on the goal of capturing the wide variety of the Danube area, while focusing on those places particularly confronted with profound sustainability transition pressures. As such, all case study regions are characterized by manufacturing and production legacies. At the same time, the regions show substantial differences with regard to prosperity, historical development paths (incl. deindustrialization processes of varying severity) and innovation capacities (Authors, 2024).

**Table 2: Overview: case study regions**

Case study regions (NUTS-Code)	NUTS-2 regions (NUTS-Code)
Lower Austria (AT12)	Lower Austria (AT12)
Ústí region (CZ042)	Northwestern Czechia (CZ04)
Schwarzwald-Baar-Heuberg (DE135/136/137)	Freiburg (DE13)
Virovitica-Podravina (HR022)	Pannonian Croatia (HR02)
Sisak-Moslavina (HR028)	Pannonian Croatia (HR02)
Hajdu-Bihar (HU321)	Northern Great Plain (HU32)

North East (RO21)	North East (RO21)
Moravica District (RS214)	Sumadija and Western Serbia (RS21)
Branicevo district (RS222)	Southern and Eastern Serbia (RS22)
Podravje-Maribor (SI032)	Eastern Slovenia (SI03)
Banska Bystrica (SK032)	Central Slovakia (SK03)

In order to map and analyze the geographies of vulnerability and preparedness to industrial transitions, we draw inspiration from recent contributions, such as the measures of regional development traps (Diemer et al., 2022), the Regional Green Transition Vulnerability Index (Rodríguez-Pose and Bartalucci, 2023), and the “REgional Societal Challenges-Oriented Readiness” score (RE-SCORE) (Cappellano et al., 2022).

Following the conceptual considerations outlined above, **vulnerability** is understood as being determined by regional industrial structures. Some vulnerability metrics (see, for instance, Rodríguez-Pose and Bartalucci, 2023) rely on comprehensive composite indicators, encompassing not only vulnerability associated with specialization in emission and energy-intensive industries, but also vulnerability arising from specialization in other sectors such as agriculture or tourism. Focusing on RITs and regional vulnerability to climate change mitigation policies, we specifically consider regional emission and energy intensities related to industrial structures. Moreover, we accord attention to changes in these indicators to account for regional development dynamics. Therefore, our measure consists of two stock and two dynamic indicators:

- the relative employment concentration in energy-intensive industries;
- the change in relative employment concentration in energy-intensive industries;
- the greenhouse gas (GHG) emissions of manufacturing activities;
- the change in GHG emissions of manufacturing activities.

Our measure of relative employment concentration relies on NUTS-2 level employment data (Eurostat) and is based on a calculation of the location quotient (LQ) of industries classified as energy-intensive by the European Commission (2020). Regional GHG emissions of manufacturing data draw on the comprehensive information provided by Crippa et al. (2023). Detailed information about the indicators, underlying data and the calculations for the vulnerability index are found in the Appendix.

To measure the **preparedness** of regions for sustainability transitions, we introduce a new multidimensional indicator (Table 3).

**Table 3: The structure of the preparedness score**

Pillar	Sub-pillars	Indicators (reference years)	Source
R&D and Innovation	General innovation performance	Regional Innovation Scoreboard relative overall score (2023)	European Commission (2023)
	Specialization in green innovation	Sustainability-related* publications per 100,000 inhabitants (2015–2021)	KNOWMAK-RISIS Database

		Sustainability-related* patents per 100,000 inhabitants (2015–2021)	KNOWMAK-RISIS Database
Institutions	Formal institutions	European Quality of Government Index (2021)	Charron et al. (2022)
	Informal institution	Share of votes on populist parties in the latest parliamentary election in the period 2019–2023	own collection**
		Climate change awareness (2019)	ESPON ‘Quality of Life’ project
Phasing-in potential	Renewable potential	Overall technical potential in green energies (2019)	Kakoulaki et al. (2021)
	Green diversification	Sustainability-related* FP project participation per 100,000 inhabitants (2015–2021)	KNOWMAK-RISIS Database
		The total amount of ERDF project expenditures on the low-carbon economy (2014–2020)	European Commission’s project portal
Decoupling progress	Decoupling progress	Employment change vs greenhouse-gas emission change (period 2019–2021 compared to the period 2009–2011)	ARDECO database and Crippa et al. (2023)

\* Sustainability-related fields include affordable and clean energy, clean water and sanitation, climate action, and sustainable cities and communities.

\*\* We used the 2019 edition of the Chapel Hill Expert Survey to identify ‘populist parties’.

The first pillar evaluates regions’ innovation performance, both in general terms and in sustainability-related fields (as a proxy for the reconfiguration of innovation system structures).

The second pillar assesses the institutional conditions in regions. The first sub-pillar considers formal institutions, using the European Quality of Government indicator. The second sub-pillar grasps informal institutions, utilizing the share of populist votes and the population’s climate change awareness as proxies for informal institutional conditions for industrial transitions.

The third pillar focuses on regions’ potential to transition towards greener economic structures. On the one hand, it considers regional potentials in renewable energies. On the other hand, sustainability-related project participations and expenditures are considered as proxies for green diversification potentials.

Finally, the fourth pillar indicates the progress made in phasing out unsustainable activities over the last decade (2019–2021, compared to 2009–2011). This pillar, inspired by recent work on “decoupling” emissions from economic development (Suedekum and Rademacher, 2024), contrast changes in employment with changes in regional greenhouse gas emissions.

Structural preparedness for regional industrial transitions can rest of various factors. The pillars defined and the indicators chosen are not exhaustive. Instead, they are meant to provide a balanced picture on regional assets needed to address industrial transition challenges, while not overloading the composite indicator with too many and often strongly correlated sub-

indicators<sup>2</sup>. The detailed methodological description of how the preparedness scores have been calculated is found in the Appendix.

Complementing the quantitative analyses of vulnerability and preparedness, our investigation of regional **”responsiveness”** relies on qualitative methods. In a first step, intensive qualitative document analyses have been conducted, providing a comprehensive understanding of regional preconditions, potentials, development goals, and transformative fields as well as existing challenges and barriers to sustainability transitions. Various documents, such as regional development and innovation strategies were reviewed, coded and analyzed. These insights have been instrumental in preparing for the subsequent step of conducting semi-structured in-depth interviews. Regional experts from industry, research, the public sector and civil society, possessing deep knowledge of their respective regions, shared their perspectives on assets, challenges, opportunities, and barriers. In total, 41 interviews across 11 regions were conducted, 13 of which in the three most vulnerable regions. Interviews have been transcribed, coded and analyzed based on our conceptual considerations.

## 4 Results

This section presents the results of our empirical analyses. First, we map vulnerability across all 238 NUTS-2 regions in the EU and Serbia, comparing the results of the 11 case study regions with the broader European context. Next, we assess the preparedness of the case study regions, benchmarking them against all NUTS-2 regions in the EU and Serbia. Finally, we investigate the responsiveness of the three most vulnerable case study regions.

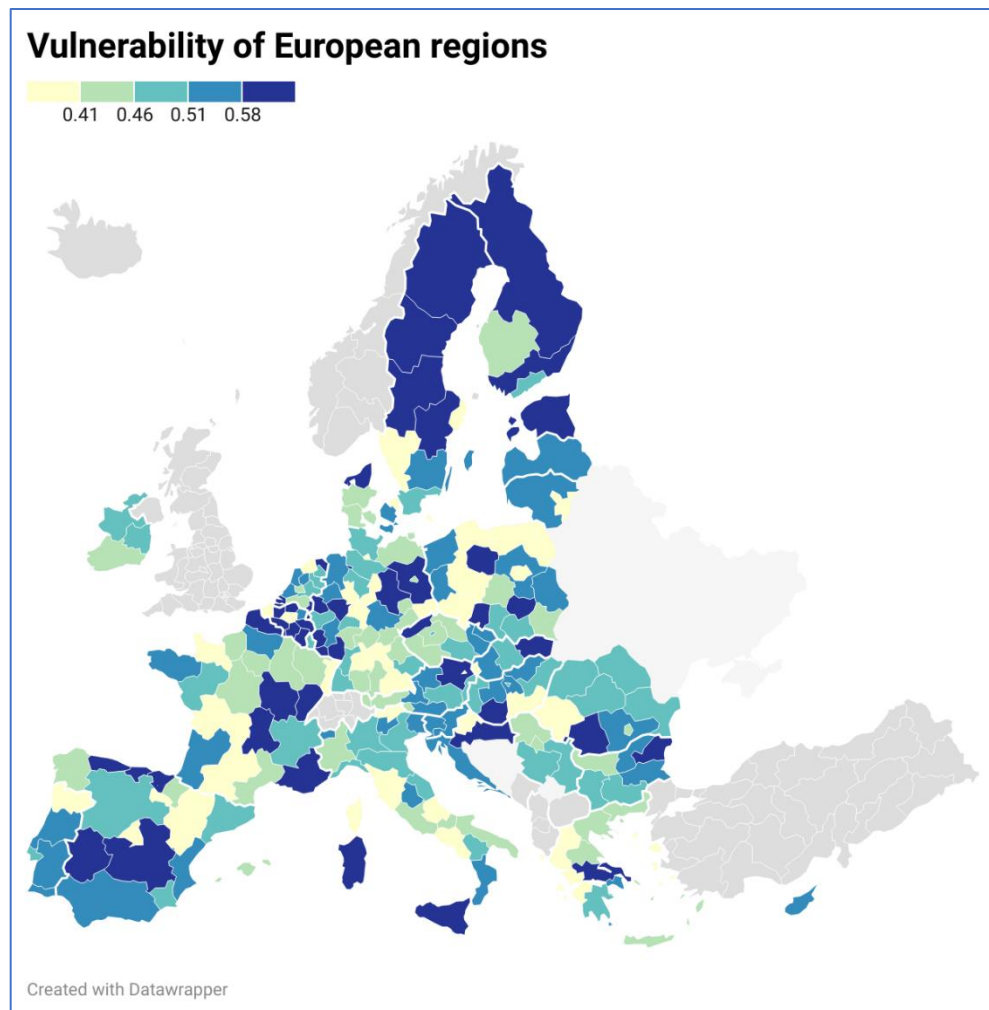
### 4.1 Mapping ‘vulnerability’ across Europe

In a first step, we identify the regions most exposed to the industrial transition imperative. Our vulnerability measure reveals a distinct geography, as shown in Figure 2. We used the quantiles to cluster the regions, resulting in five distinct groups.

**Figure 2: Vulnerability of European regions**

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<sup>2</sup> For this reason, we decided to omit GDP per capita (often considered the default indicator for reflecting (regional) prosperity) as a measure of preparedness due to its high correlation with other benchmarks in our set of indicators, like the European Quality of Governance Index and the overall innovation performance of regions.



The results exhibit that several places in Europe, like the Ruhr area in the Western and lignite mining regions in the Eastern parts of Germany, Silesia in Poland, Northern and Central Sweden and Finland, the Northwestern area of Czechia or Lower Austria, can be identified as particularly exposed to industrial transitions. This illustrates that not only less developed regions but also relatively well-off areas can be considered vulnerable.

**Table 4: Vulnerability of the case study regions**

Code	Name of NUTS-2 region	Vulnerability level (according to the clusters)
AT12	Lower Austria	<b>High</b>
CZ04	Northwestern Czechia	<b>High</b>
DE13	Freiburg	Moderate
HR02	Pannonian Croatia	<b>High</b>
HU32	Northern Great Plain	Moderate
RO21	North East	Moderate
RS21	Sumadija and Western Serbia	Moderate
RS22	Southern and Eastern Serbia	Moderate
SI03	Eastern Slovenia	Above average
SK03	Central Slovakia	Moderate

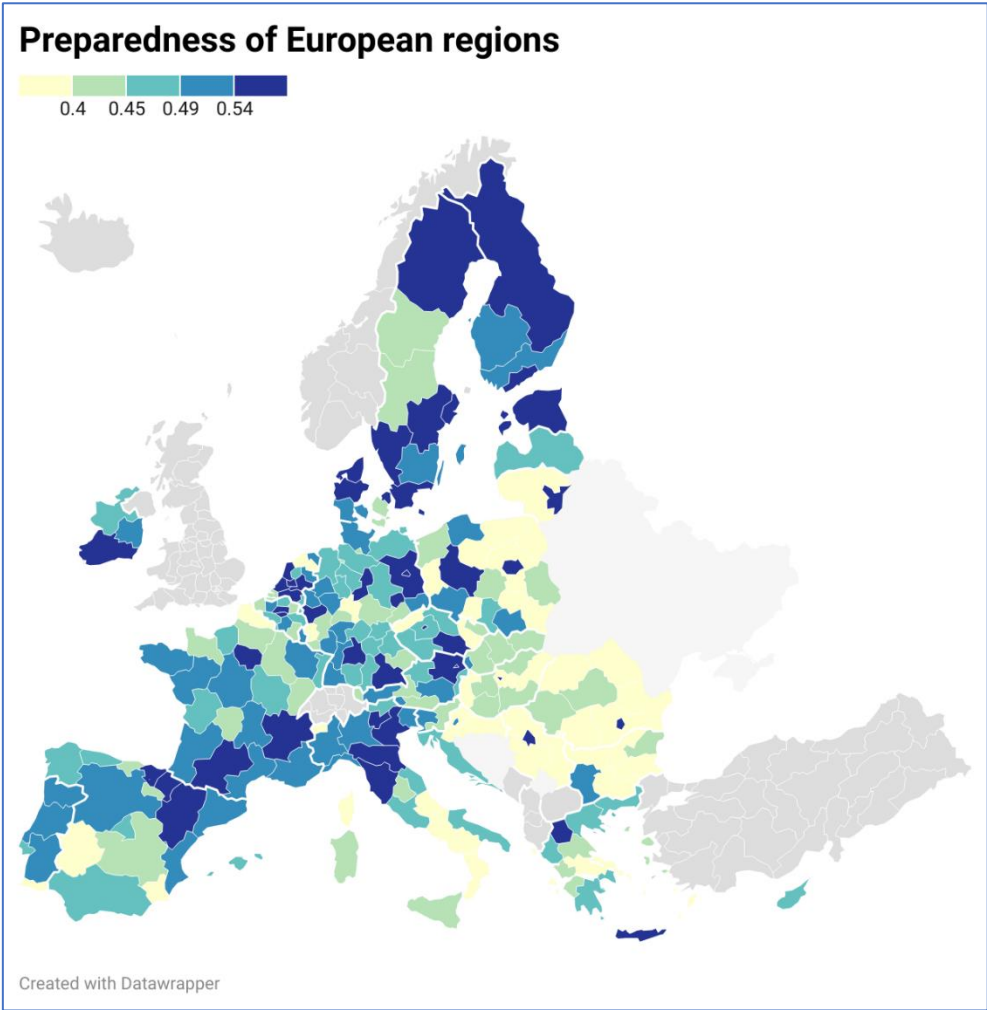
Focusing on the NUTS-2 regions where the case study regions are located, all of them face moderate to high levels of vulnerability, reflecting the manufacturing legacies of these places

(Table 4). Lower Austria, Northwest Czechia, including the Ústí region, and Pannonian Croatia, including Sisak Moslavina, are among the regions with the most vulnerable economic structures in Europe.

#### 4.2 Unravelling assets to address the transition challenge: the ‘preparedness’ of the case study regions

Having identified regional vulnerabilities to industrial transitions, this subsection analyses the asset endowments of regions to address transition challenges. Unsurprisingly, among the 238 regions in the dataset, the most developed areas exhibit the highest levels of preparedness and are primarily located in Central and Northern Europe (Figure 3). These results reflect the solid institutional configurations and strong innovation capacities of these regions.

Figure 3: Preparedness of European regions



Among the 11 case study regions (or the NUTS-2 regions in which they are located), there is a notable divide. Lower Austria (ranked 24<sup>th</sup> out of 238 regions) and Freiburg, Germany (88<sup>th</sup>), show a (relatively) high degree of preparedness, while the rest of the case study regions fall within the lowest-performing third of the sample. This indicates that the conditions for industrial transitions are relatively unfavorable in most case study areas, particularly in the

Czech (218<sup>th</sup>), Croatian (220<sup>th</sup>), Hungarian (209<sup>th</sup>), Romanian (207<sup>th</sup>), and the two Serbian regions (236<sup>rd</sup> and 237<sup>th</sup>).

In a next step, a more detailed analysis of the pillars and sub-pillars of preparedness is provided to uncover the regions' relative strengths, opportunities and possible transition pathways (Figure 4).

**Figure 4: Preparedness of case study regions**

Region	Overall preparedness ranking (in 238 regions)	Overall preparedness score	General innovation performance	Specialisation in green innovation	Formal institutions	Informal institutions	Renewable potential	Green diversification	Decoupling progress
AT12	24	0.575	0.750	0.511	0.813	0.486	0.673	0.595	0.388
CZ04	218	0.326	0.261	0.164	0.502	0.408	0.340	0.410	0.261
DE13	88	0.496	0.732	0.670	0.728	0.482	0.400	0.333	0.311
HR02	220	0.319	0.188	0.296	0.111	0.480	0.538	0.473	0.232
HU32	209	0.356	0.300	0.238	0.370	0.511	0.493	0.331	0.304
RO21	207	0.367	0.416	0.369	0.329	0.448	0.599	0.252	0.261
RS21	237	0.286	0.240	0.114	0.492	0.071	0.350	0.338	0.342
RS22	236	0.289	0.253	0.147	0.492	0.065	0.397	0.346	0.307
SI03	160	0.432	0.442	0.314	0.569	0.486	0.436	0.489	0.361
SK03	170	0.426	0.364	0.481	0.666	0.340	0.355	0.481	0.362

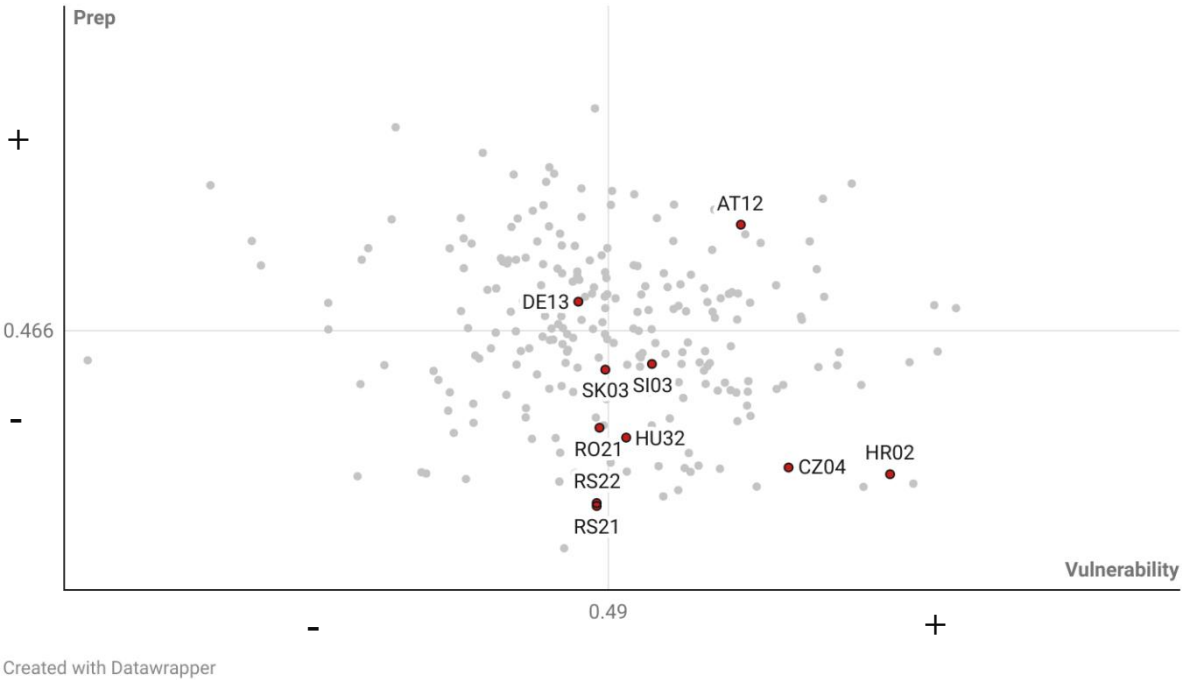
The first pillar scrutinizes the innovation potential of regions. As expected, the overall innovation performances (sub-pillar 1) of the investigated Austrian and German regions markedly surpass those of other case study regions. However, the second sub-pillar (specialization in green innovation), considered as an indicator for the re-orientation of the RIS towards territorial challenges (Isaksen et al., 2022), reveals intriguing insights. Some regions (Central Slovakia, Pannonian Croatia) show a promising result here, despite their modest overall innovation performance. In other regions such as Lower Austria, Northwestern Czechia and the Serbian case study regions, progress made thus far in advancing green innovation lags behind the general innovation capacities.

The second pillar examines the institutional conditions shaping regional transitions. While formal institutions vary considerably among the case study regions, there is comparatively less divergence concerning informal institutions. Only the Serbian regions are outliers in this regard, significantly lagging behind in terms of climate change awareness. This deficiency poses substantial barriers to transition processes.

The third pillar focuses on potentials for transitioning towards new green activities. Two sub-pillars are considered: the renewable energy potential and green diversification efforts. The renewable energy potential demonstrates a notable disparity compared to the other dimensions of preparedness. This indicates the emergence of new energy geographies and underscores the potential these sources might offer to several vulnerable, less-developed regions with limited asset endowments in other domains (e.g., Nord-Est or Pannonian Croatia). In comparison, the green diversification sub-pillar (measured by project participation in sustainability-related or low-carbon economy projects), presents a relatively balanced picture across regions (with Lower Austria outperforming and Nord-Est slightly underperforming).

The decoupling pillar illustrates the progress made in transitioning away from and replacing brown activities. Higher scores indicate that a region has made significant advancements in reducing emissions while maintaining or increasing employment levels. Lower Austria, Eastern Slovenia, and Central Slovakia are the best-performing regions in this regard. In contrast, highly vulnerable regions such as Pannonian Croatia and Northwestern Czechia still have a long way to go in decoupling employment and emissions.

**Figure 5: Regional positions in the dimensions of vulnerability and preparedness**



So far, our analyses revealed the uneven geographies of vulnerability and preparedness. Conceptually, we consider both vulnerability and preparedness, as key dimensions of the structural conditions of regions. Therefore, comparing the two measures highlights how the exposure of places to industrial transitions compares to their capacities to address the challenges posed by transitions.

Figure 4 contrasts the vulnerability of the 11 case study regions (red dots) and the other 227 places in the sample (grey dots) with their preparedness. This reveals that many regions exhibiting significant vulnerability to industrial transitions lack key assets required for facilitating transformative change (bottom right corner). In other words, many regions that are in need of restructuring their unsustainable industrial fabrics are poorly positioned to do so. Specifically focusing on the case study regions, only Lower Austria and Freiburg, the most developed regions among the case study areas, surpass the overall average in terms of preparedness; all other places fall below this threshold. Regarding vulnerability, three regions are notably among the most vulnerable ones: Lower Austria, Sisak-Moslavina (Pannonian Croatia) and Ústí (Northwestern Czechia).



### 4.3 Investigating responsiveness in three vulnerable regions: the cases of Lower Austria (AT), Ústí (CZ) and Sisak-Moslavina (HR)

The previous subsections centered on structural conditions and highlighted the distinct geographies of vulnerability (exposure to industrial transitions) and preparedness (conditions and capacities to cope with transition imperatives). This subsection examines the responsiveness of selected RITs. As a detailed investigation of all 11 regions in our data set would be beyond the scope of the article, we focus here on those regions that exhibit the highest level of vulnerability owing to their industrial structures: Lower Austria, Sisak-Moslavina and Ústí<sup>3</sup>. Despite sharing this common challenge, these areas differ significantly in terms of their preparedness.

Lower Austria stands out as the most prepared region among the three areas, presenting an intriguing case of a region with both substantial transition needs and strong transition capabilities. The region's preparedness is underpinned by its renewable energy potential, strong institutional framework conditions (particularly formal institutions), an above-average innovation performance, strong green diversification potential along with progress in phasing-out non-sustainable activities.

In contrast, Ústí is among the least prepared regions, performing below average across all pillars. While its institutional framework conditions are nearly on par with peer regions, a combination of poor innovation performance, little evidence of RIS reorientation, weak phasing-in potentials, and limited progress in decoupling economic development from emissions render transition processes in this highly vulnerable Czech region particularly challenging.

Pannonian Croatia faces a similarly intricate situation. While being somewhat better prepared to address its transition challenges, especially due to its renewable energy potential and informal institutional conditions, the overall weak asset endowments and the Petrinja earthquake in 2020 leave the region in a rather unfavorable position.

These cases allow for a comparative analysis of regional responsiveness, examining how regional and non-regional stakeholders respond to and interact with varying structural preconditions to drive or resist industrial transition processes. We draw on the conceptual considerations outlined in Section 2 to compare four key agentic processes in the three RITs.

This first core process focuses on the identification of territorial **challenges and the assets needed to address them**. In this regard, our investigation in Lower Austria has revealed a widespread awareness of historically grown strengths, the region's asset base, and industrial culture. However, the identification of challenges is contested. Ambitious change agency is held back by a strong belief that industrial transitions might render previously developed competitive edges obsolete, highlighting conflicts between economic and ecological goals (Authors, 2024). These tensions are perhaps best illustrated by a recent statement by Johanna Mikl-Leitner, the provincial governor of Lower Austria. Shortly before the 2024 European parliament election, she argued:

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<sup>3</sup> All three regions are (at least partly) considered by the EU's Just Transition Funds (JTF).

*“Climate protection is important, but so is the competitiveness of our Lower Austrian firms and the prosperity of the people of Lower Austria. We do not need an over-regulated European Union that is increasingly becoming a green NGO [...].” (OTS, 2024)*

In contrast, Ústí, characterized by an eroded asset base (Blažek et al., 2023), exhibits a more profound and widespread urgency to act due to a heightened awareness of challenges. This is exemplified, for instance, by the national RE:START program, a plan for transforming the coal-dependent and heavy machinery regions of Czechia (including Ústí) that highlights the concentration of vulnerable sectors as a mandate for action. As a regional development officer (RDO) summarized it:

*“In the past it was very difficult because actors wanted to preserve the traditional industry [...] now they recognize that it is really over. And I think now they are more open for new development paths. [...] This [mining and traditional industrial activities] is the past and what we need is to reconstruct the structure of our economic branches.”*

At the same time, there were reports that an “old industrial mindset” (interview with a university researcher) still exists, leading to an overly strong focus on preserving unsustainable economic models while neglecting transition needs.

Similarly, industrial transitions rank high on policy agendas in Sisak-Moslavina. For instance, the Pannonian Croatian Industrial Transition Plan states: “Pannonian Croatia, as a region in industrial transition, is faced with [...] the gradual abolition of traditional industries” (p. 50), indicating a clear awareness of pressing challenges. Interestingly, according to regional experts, the recent earthquake contributed to a re-evaluation of challenges and spurred agentic processes the region, not least due to an increase of external financial support. However, the emphasis on rebuilding destroyed assets has overshadowed other challenges, notably the industrial transition imperative:

*“Still, the reconstruction of public buildings, homes, roads, bridges, is the number one question. So, you will not hear many public debates about [...], transitions and the transformation of the economy.” (RDO; Sisak Moslavina)*

Linked to the awareness and identification of challenges and assets, different **search processes for innovative solutions** are observed in the three regions. In Lower Austria, a strong focus on transition efforts based on existing assets was found, reflecting an incremental re-orientation of innovation system structures rather than more radical transformation (Isaksen et al., 2022) as the predominant strategy. This is mirrored in a rather underwhelming green innovation performance (compared to the strong general one). Nevertheless, regional actors have recently succeeded in exploiting the renewable energy potential, especially wind, and adopting circular economy principles in certain fields. Despite this progress, transition processes are hindered by incumbents’ maintenance agency, especially in industries reliant on fossil resources (see also Steinböck and Tripl, 2023):

*“So, we have a huge obstacle in the fact that the fossil industries, particularly gas, are very important. [...] So, those who are attached to it or are somehow connected to it, in my opinion, are really quite actively hindering the transition”* (Policy expert; Lower Austria)

In Ústí, we encountered highly ambitious transition goals that have spurred action and yielded some promising results in the past, particularly in improving the region’s air quality (Czech Statistical Office, 2021). However, regional actors are often handicapped by weak structures and limited preparedness (see also Blažek et al., 2023). Consequently, change agency is driven by bold visions of diversifying into fields such as renewables, hydrogen, robotics, nanotechnology and automated mobility. All of these are highlighted as new development areas in Czechia’s smart specialization strategy’s section on Ústí (MPO, 2021). Yet, these ambitions are often not matched by the necessary assets. One researcher in the region summed it up as follows:

*“I think one of the greatest problems [is] that the basement is quite weak, especially in new areas. Historically, this region wasn’t connected with such activities, with hydrogen, with robotics, with this new economic branches and trends and this is quite a serious problem [...]”*

In Sisak-Moslavina, a newfound belief in a better future have spurred innovation. Transition processes and new development paths have emerged in the domains of ICT (gaming industry), renewable energy, tourism, and smart and organic agriculture. However, similar to Ústí, an unfavorable asset base (evidenced, for instance, by low levels of patenting), outmigration (marked by strong negative net migration since 2011) and a mismatch between supply and demand on the regional labor market constitute fundamental barriers to change according to the regional development office (rk-smz, 2023).

Another parallel between the Czech and the Croatian case lies in the significant role of extra-regional influences. National and supranational programs play a crucial role in driving agency in both regions. However, structural deficiencies (e.g., skilled workforce, lack of educational institutions, ...) might impede the successful implementation of innovative solutions:

*“European acts are too progressive in some way for things we needed to do. You cannot innovate if you don’t have basic infrastructure.”* (Regional expert; Sisak-Moslavina)

The third core process, **unlocking unsustainable development paths**, is a delicate matter in highly vulnerable regions. In Lower Austria, exnovation, often induced by EU policies rather than regional agency, is met with strong skepticism. In a recent survey conducted by the Lower Austrian branch of the Federation of Austrian Industries (‘Industriellenvereinigung’) among its members, more than 90% of respondents expressed doubts about the feasibility of both European and national emission reduction targets (Datzreiter, 2022). This fits the picture that the region is indeed struggling to reduce GHG emissions in its manufacturing sector. However,

it should be noted that the region has demonstrated decoupling progress in other fields (e.g., due to growing exploitation of renewable energy resources, see Figure 4).

As noted above, the need to dismantle old structures is widely accepted in the Ústí region. Exnovation pressures are a result of both domestic (often referring to economic reasons such as falling coal prices or a decrease in production rather than climate concerns; WKI, 2021) and supranational policy influences. However, the actual progress made thus far falls short of the ambitious goals, indicating that there is still a long way to go (Figure 4).

Our results suggest that the situation in the Croatian region presents an even greater level of complexity. On the one hand, exnovation is viewed as an opportunity to venture into new strategically important fields and to create space for change agency. The Industrial Transition Plan, for instance, underscores new opportunities “*to enable the modernization and diversification of the regional economy*” (p. 61) arising from phasing-out carbon intensive activities. On the other hand, experts have highlighted a deficiency in legitimacy and limited progress in Sisak-Moslavina, not least due to the county’s history:

*“This transition process, I mean, transition from socialism to capitalism was not smooth. [...] this transition nowadays is seen as criminal [...] So even the word transition is very sensitive here, you know. [...] So, we are very careful not even to use this word [in our work with the JTF]. We are trying to find something less provocative.”* (Regional expert; Sisak-Moslavina)

The fourth core process focuses on the **orchestration** of the interests and activities of multiple regional stakeholders. In Lower Austria, known for its strong but often closed networks, coordination is effective but tends to steer agency towards incremental changes, if not preservation. This dynamic is increasingly in conflict with mounting transition pressures and leads to an unclear industrial transition path:

*“In comparison [to digitalization], I have the clear impression that in relation to a sustainability transition, it is not yet so precisely structured what needs to happen”.* (RDO; Lower Austria)

In Ústí, regional actors have started to orchestrate transition activities, in particular those related to the JTF and the national RE:START program. However, our interview partners emphasized that the lack of a clear and realistic direction, along with the fragmentation of the RIS, remain fundamental issues (see also Blažek et al., 2023). Therefore, there is a need for enhanced coordination, which is also acknowledged in the region’s innovation strategy (Ústecký kraj, 2024). This is paramount considering the significant influx of financial resources into the region, which can potentially lead to conflicts of interest:

*“Our region gets great resources for transformation. [...] We are in a time of negotiation about which project will be the best and it is quite difficult because there are many ... interests, of course.”* (RDO; Ústí)

Likewise, in Sisak-Moslavina, the regional development office SI-MORA has played a proactive role in orchestrating transition efforts. One actor from industry stated: “*they have made all those things [new industrial development paths] possible*”. However, another interviewee emphasized the critical need to enhance these endeavors. It is essential to rally stakeholders around a shared vision for industrial transitions, create legitimacy and capitalize on the recent regional momentum generated in response to the earthquake and floods:

*“I think it is a very big challenge to ... improve the transition process, how to put other people on this bus, you know. So, they all go into the same direction. So, this is now quite a challenge.”* (Researcher; Sisak-Moslavina)

## 5 Conclusions

In this final section, we reflect upon the empirical findings to distil some key learnings and we draw implications for the design of future-proof place-based industrial transition strategies.

### 5.1 Discussion and reflection

In this article, we have argued that regional transitions are the outcome of an interplay of vulnerability, preparedness and responsiveness. We have emphasized that it is necessary to combine structure and agency perspectives, and quantitative and qualitative methods, to analyze the complexity underpinning sustainability shifts in RITs.

Conceptually, drawing inspiration from recent work on green regional vulnerability, challenge-oriented regional innovation systems and transformative resilience, we have developed a framework we consider suitable to grasp the uneven geography of industrial transitions (Figure 1). Based on this framework, we have distinguished between four ideal-type industrial transition pathways in vulnerable regions depending on different configurations of preparedness and responsiveness (Table 1).

Empirically, we have mapped the vulnerability to and preparedness for industrial transitions across 238 European NUTS-2 regions (Figure 2 & Figure 3). This has revealed that many regions that are in need of restructuring their unsustainable industrial fabrics are poorly positioned to do so (see regions in the bottom right of Figure 5), indicating substantial transition challenges and, potentially, disruption risk ahead for these places (Martin et al., 2022).

We have also examined the uneven geographies of vulnerability and preparedness in 11 case study areas. For the three most vulnerable places (Lower Austria, Ústí (Czechia) and Sisak-Moslavina (Croatia)), we have also examined their responsiveness and how it is shaped by different forms of agency.

Our approach to measuring vulnerability, centered on employment concentration in energy-intensive industries and emission intensities of manufacturing activities, has demonstrated that all three regions are highly exposed to potential disruptions due to climate change mitigation policies. However, they exhibit pronounced differences in their preparedness. Moreover,

regional as well as non-regional actors interact with structural vulnerabilities and preparedness conditions in different ways, leading to distinctly different ongoing transition pathways.

In Lower Austria, high vulnerability meets high preparedness. The region is well endowed with different assets and holds strong capacities for transitions. However, orchestration of efforts is often oriented towards incremental change, if not maintenance of old structures and active resistance to change by powerful incumbents. Accordingly, Lower Austria's transition path currently lags behind the region's potential and therefore strongly resembles a *complacent* transition pathway (Table 1). However, recent successes in certain fields (renewables, circularity) should not go unnoticed. They are a demonstration of more ambitious forms of responsiveness and, hence, an indication of a more *pioneering* transition pathway.

In the Ústí region, high vulnerability paired with limited preparedness is rendering transition processes in the Czech region extremely intricate. Yet, despite an eroded asset base or perhaps precisely because of it, the awareness of challenges is very high. In conjunction with external money flowing into the region, visions for transformative change have been developed, but they are often ill-aligned with the region's capacities. Hence, Ústí's current transition path, characterized by a mismatch between ambition and feasibility, lacks a clear and viable way forward. This situation points to an *overreaching* transition pathway, even though inconsistencies in responsiveness based on an '*old industrial mindset*' have also been found.

In Sisak-Moslavina, the region's history and recent natural disasters tend to overshadow the industrial transition challenge. Nevertheless, some promising steps have been taken recently, for instance in the field of renewable energies. However, a lack of legitimacy for industrial transitions and limited preparedness lead to a transition that faces difficulties in taking off. The situation in the Croatian region is best described as an *overreaching* industrial transition pathway that is, however, strongly contested and, hence, includes some characteristics of a more *stagnant* pathway.

These different pathways demonstrate the complexity and controversies that underpin industrial transitions, conceptualized here as the outcome of structure-agency dynamics. We contend that these empirical insights hold two important lessons.

First, they show that the four pathways of industrial transitions in highly vulnerable regions that were identified in conceptual terms (Table 1) are indeed ideal-types. Inconsistencies in the responses to transition pressures in Lower Austria, Ústí and Sisak-Moslavina demonstrate the contested nature of agentic processes on the ground. These controversies and struggles over transitions can translate into hybrid pathways that combine features of different types. Still, we argue that the typology is a helpful heuristic to better capture the variety and complexity of regional industrial transition processes that often remain underappreciated in current debates.

Second, our analyses point to the need to broaden scholarly discussions on RITs, which have thus far centered around structural conditions and related regional vulnerabilities to industrial transitions (OECD, 2023; Rodríguez-Pose and Bartalucci, 2023). More research is required to further unravel the preparedness of (particularly exposed) places to address territorial transition challenges. Equally important, future studies on RITs need to better account for the ways in

which actors make sense of and exploit variegated structural conditions in their efforts to drive, but also hinder, regional industrial transitions.

## **5.2 Implications for future-proof place-based industrial transition strategies**

Insights into the uneven geographies of vulnerability, preparedness and responsiveness hold important implications for the design and implementation of place-based industrial transition strategies. The analyses of Lower Austria, Ústí and Sisak-Moslavina have shown that current programs, like the JTF, are too narrow in their approach, insufficiently accounting for the varying structural preparedness of regions (e.g., due to the lack of legitimacy for transitions), and issues such as stakeholder engagement, inclusivity and orchestration (e.g., tensions between stakeholders with varying degrees of power, lacking coordination capacities, etc.).

While it is beyond the scope of this article to provide a comprehensive outline of a more holistic policy approach to RITs, our conceptual model and empirical learnings offer some room for reflection. Accordingly, future place-based industrial transition strategies should more accurately consider structural conditions, agentic processes and their dynamic interplay.

As regards regional structures, current policy programs are often focused on short-term relief and technological fixes rather than longer-term reconfigurations of innovation systems and the bolstering of preparedness. Arguably, perspectives like CORIS (Tödtling et al., 2022) and scholarly contributions dealing with the development of more challenge-oriented RIS configurations (Isaksen et al., 2022) can provide guidance in bringing about structural conditions more conducive to transformative change in RITs. They emphasize the importance of reorienting the existing regional asset base, but also the necessity of more radical forms of structural reconfiguration through the transplantation or creation of new and the dismantling of old assets, especially in RITs suffering from a lack of structural preparedness (Isaksen et al., 2022). Arguably, such regions will often have to rely on longer-term policy support capable of altering structures that have evolved over an extended period of time (Baumgartinger-Seiringer et al., 2022).

In addition, industrial transition policies should better account for the varying degrees of regional responsiveness. In settings of low responsiveness, policymakers should aim at empowerment, leadership and vision-building (Beer et al., 2023) to enhance change agency. However, low responsiveness might (also) be the result of lock-in and active resistance to change (see the case of Lower Austria). Therefore, such settings might demand path-breaking policies (Heyen et al., 2017), for instance in the form of withdrawing support for ‘the old’ or rebalancing actor networks (Kivimaa and Kern, 2016). In settings of high responsiveness, policymakers should implement measures geared towards reinforcing, sustaining and consolidating existing activities (Bækkelund, 2021). This is especially important in RITs on an *overreaching* transition pathway (low preparedness, high responsiveness; Table 1), as in such places, change agents are at risk of being quickly discouraged by the lack of structural support (‘straw fire scenario’).

Ultimately, the understanding of regional industrial transition pathways proposed in this article implies the need for comprehensive policy mixes depending on the concrete preparedness-

responsiveness configuration in RITs. We contend that there is merit in extending this discussion in future research.

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