Kostarakos, Ilias; Marques Santos, Anabela; Molica, Francesco

Working Paper

Regional resilience in the era of climate change and digitalization

JRC Working Papers on Territorial Modelling and Analysis, No. 08/2025

Provided in Cooperation with:
Joint Research Centre (JRC), European Commission

European Commission

JRC WORKING PAPER

Regional resilience in the era of climate change and digitalization

JRC Working Papers on Territorial Modelling and Analysis

No 08/2025

Authors:

Kostarakos, I.

Marques Santos, A.

Molica, F.

2025

Joint Research Centre

The **JRC Working Papers on Territorial Modelling and Analysis** are published under the supervision of Simone Salotti, Andrea Conte, and Anabela M. Santos of JRC Seville, European Commission. This series mainly addresses the economic analysis related to the regional and territorial policies carried out in the European Union. The Working Papers of the series are mainly targeted to policy analysts and to the academic community and are to be considered as early-stage scientific papers containing relevant policy implications. They are meant to communicate to a broad audience preliminary research findings and to generate a debate and attract feedback for further improvements.

Contact information
Name: Anabela M. Santos
Address: Edificio Expo, C/Inca Garcilaso 3, 41092 Sevilla (Spain)
Email: anabela.MARQUES-SANTOS@ec.europa.eu
Tel.: +34 95 448 71 61

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC139516

Seville: European Commission, 2025

How to cite this report: Kostarakos, I.; Marques Santos, A.; Molica, F., *Regional resilience in the era of climate change and digitalization*, European Commission, Seville, 2025, JRC139516.

Contents

Abstract

The impacts of the green and the digital transitions on the regional economic structure of the European Union are of paramount importance and have been at the forefront of the recent policy discussions. This paper contributes to the ongoing discussion by developing a composite indicator to assess the overall risks imposed by the twin transition on the EU's NUTS2 regions. The indicator focuses on two key aspects: the regions' vulnerabilities and their readiness to adapt to the challenges of the transition. The risk index highlights the large degree of heterogeneity in terms of the risk imposed by the transition process, with the less-developed regions emerging as the most vulnerable.

Acknowledgements

The authors are grateful to Elena Kostadinova, Wolfgang Munch and Vincent Leiner from European Commission's Directorate-General for Regional and Urban Policy (unit G1) and Maria Batalla Masana from Directorate General for Internal Market, Industry, Entrepreneurship and SMEs (unit D2) for their valuable comments and suggestions. The authors also thank the participants in the XLV AISRe Annual Scientific Conference and XLVIII International Conference on Regional Science for suggestions received.

Authors

Ilias Kostarakos (corresponding author)
Ilias.KOSTARAKOS@ec.europa.eu

Anabela Marques Santos
anabela.marques-santos@ec.europa.eu

Francesco Molica[1]
Francesco.MOLICA@ec.europa.eu

Keywords: Twin transition; Regional vulnerability; Regional readiness; European Union.

JEL Code: O30; O44; Q56; R11

1 Now at Université libre de Bruxelles, Solvay Brussels School of Economics and Management, Brussels, Belgium. Email: francesco.molica@ulb.be.

Executive summary

Climate change and the ever-increasing digitalization of the various economic sectors, driven by recent advances in automation and machine learning, are expected to have a significant impact on the regional economies of the European Union. Regions are undergoing a process of change known as the twin transition, which will likely modify their productive structure and affect employment.

In this context, the paper aims to provide a measure that can capture both the risk aspects embedded in a process of structural transformation akin to the twin transition, as well as the regional economies of the EU's readiness for it. Drawing inspiration from the concept of risk from the JRC Risk Data Hub, where risk is defined as the combination of vulnerability, hazard and exposure, we aim to capture the dimensions of the expected impact of the twin transition. Moreover, we consider readiness as a concept encompassing characteristics that can counteract the risk factors and can assist the regions in successfully completing the transition process.

This composite indicator can then be used to identify regional patterns, assess which are the regions that are more exposed and vulnerable to the changes brought about by the ongoing transition, and reveal the factors behind regions' differing abilities to counteract the transition's disruptive effects.

Our analysis reveals several interesting facts. Firstly, a significant degree of heterogeneity emerges in the distribution of the risk across the EU regions, with those located in the southern periphery being the more vulnerable ones. Secondly, we observe a strong correlation between a region's relative position in the income distribution and its level of risk, as measured by the proposed indicator. Specifically, less-developed regions (and, to a lesser extent, regions in transition) are the ones that exhibit the highest level of risk. Lastly, using of the development trap index of Diemer et al. (2022), we demonstrate that regions at higher risk of economic stagnation will be most negatively affected by the twin transition.

1. Introduction

All regions of the world are facing a dual societal challenge stemming from climate change and digitalization. Climate change threatens ecosystems, amplifies natural disasters, and jeopardizes food and water security (Muluneh, 2021). Advances in digital technologies, such as automation and artificial intelligence, have the potential of heavily impacting labour markets, causing changes in the tasks performed by workers, leading to job displacement or job losses (see, among other, Acemoglu and Restrepo, 2018, 2019, 2020; Acemoglu et al., 2020; Brynjolfsson and McAfee; 2014 and Filippi et al., 2023) while also exerting an effect on the trajectory of inequality (Acemoglu, 2025; Acemoglu and Restrepo, 2022; Helsper, 2021).

To mitigate the effects of climate change, the European Commission has launched several policy initiatives since 2019 to ensure a transition to a climate-neutral economy by 2050, while simultaneously fostering economic growth and social equity. At the same time, the inevitable transition to a more-digital economy, with the rapid expansion of artificial intelligence and automation, is having an impact on production processes (Jämsä-Jounela, 2007) and the labour market (Filippi et al., 2023). The effects of this transition are not uniform. Rather, across the EU regions, the impact is expected to be rather heterogeneous as some regions are more exposed to the green and digital transition due to their economic structure, labour force skills, investment dynamics, financing opportunities as well as geography (see e.g. Rodríguez-Pose and Bartalucci, 2024). On the other hand, economically vibrant and technologically advanced regions, especially those home to large metropolitan areas, are likely to benefit extensively. In other words, the green and digital transition carries the risk of creating regional winners and losers, further entrenching – or, even, amplifying - territorial disparities at a time in which regional convergence was already slowing down or even reversing (Roses and Wolf, 2021). Eventually, the expected uneven distribution of the effects of the green and digital transitions could lead to a rise in regional discontent, as documented in Rodriguez-Pose and Bartalucci (2024) and this divide between winners and losers could imperil the very ambitions of decarbonizing and digitizing Europe's economies (European Commission, 2024). Understanding the extent to which the regional economies of the EU are vulnerable to the effects of the transition and the degree to which they are ready to face the upcoming challenges is crucial for policymakers to better target their policy responses and ensure that no one is left behind.

The present paper aims to develop a composite indicator allowing the identification of European regions more exposed to the negative effects of this transition and those more prepared for it. The proposed indicator aims to capture two important aspects of the ongoing transition, namely, vulnerability and readiness. In this context, vulnerability broadly captures the risks that a region is likely to be exposed to while on the transition path. To be more specific, one can think of vulnerability as being related to factors impeding a smooth transition to a greener economy with lower risks for employment, such as the level of greenhouse gas emissions and the concentration of employment in sectors identified as being the most polluting, as well as regional characteristics amplifying the risks associated with the disrupting effects of digitalization, automation and new technologies on employment. These risk proxies highlight the potential negative effects of the twin transition on regional economic performance. On the other hand, readiness is taken to encompass the factors which ensure that a region in well-equipped to counteract the aforementioned risks, swiftly adjust to the emerging new paradigm and reap the benefits of the opportunities that will arise during (or, as part of) the transition. As an example of such factors, one can consider the case of regions that have access to EU funds which were earmarked to support the green and digital transition during the last programming period or regions that have a higher technological and innovation capacity as measured by the levels of green and digital patent applications etc. These regions could be considered as being more ready, that is, in a better position to adjust and adapt to the needs of the transition process.

To the best of our knowledge, nearly all studies on the spatial implications of the twin transition (see next section) tend to focus on either of the two dimensions, with the majority of the research contributions focusing on the green transition. The novelty of our analysis is that it seeks to investigate the vulnerability and the readiness aspects of both dimensions of the ongoing transition, in order to comprehensively determine the position of regions vis-à-vis the twin transition.

From a technical perspective, the construction of the composite indicator is based on the geometric aggregation approach, in which the various sub-indices enter multiplicatively and each is assigned a specific weight. This approach allows for a large degree of flexibility, as it allows the policymaker to examine the impact of different assumptions regarding the weighting scheme. As such, a number of alternative scenarios can be formulated and assessed, leading to –arguably- more robust conclusions.

To this end, a number of different datasets were combined in order to generate all the components of the proposed composite indicator. In particular, we employed data –among others - from Eurostat and ARDECO for (macro)economic statistics, JRC-EDGAR for emissions as well as from the Regional Competitiveness Index and the Regional Innovation Scoreboard. A more detailed description is presented in the relevant section below.

The main results of this paper can be summarized as follows: firstly, we observe a significant degree of regional heterogeneity with respect to the potential impact of the ongoing industrial transition. In particular, our results suggest that regions in the southern periphery of the EU and regions located in Central and Eastern Europe are more vulnerable to the risks posed by the transition process. Secondly, our evidence suggests that the (relative) income level of regions and the level of risk are negatively correlated. Specifically, lagging-behind regions at the lower end of the income distribution face a higher level of risk, while the relatively richer regions exhibit significantly lower indices for both aspects of the industrial transition. Finally, regions facing the highest risk of falling into a vicious circle of economic stagnation, as measured by the Diemer et al (2022) Development Trap index, exhibit high levels of risk for both the green and the digital transitions.

The rest of the paper is organized as follows: section 2 provides a brief review of the relevant literature, while section 3 describes the data employed and the methodological approach utilized for the construction of the proposed indicator. Section 4 presents the results and section 5 offers some concluding remarks.

2. Related Literature

There is a rapidly expanding body of literature exploring the economic impact of the ecological and digital transition. A key angle on which emphasis has been placed concerns the effects on the labour market. Research in this area exhibits some consensus on the fact that the aggregate impact of the ecological transition on employment will likely be marginal (see for instance: Fragkiadakis et al., 2023; Vandesplas et al., 2022; Bergant et al. 2022). However, expected shifts between occupations, sectors, and firms have significant distributional implications, including from a spatial standpoint. Many regions that are more vulnerable or less ready to adapt to the green transition because of their production structure (e.g. carbon intensive industries) or technological capacities are either low-income ones or regions that were already experiencing a long-term decline due to the de-industrialization process of the past decades (Roses and Wolf, 2018; Weber, 2020). The transition is likely to compound their plights because of the direct effects in terms of jobs losses as well as negative externalities resulting from this (see Vona, 2022). Vulnerability is also projected to rise in wealthy regions which are home to industries undergoing profound transformations, such as the automotive one (European Commission, 2022). Additionally, Maucorps et al. (2023) point out that less developed regions will generally have to invest more to meet the targets of the transition, because of their more energy intensive housing and transport sectors; however, these are regions that have a smaller investment capacity. This might result in diverting funds from other types of (potentially productive) investment with negative effects on long term growth.

As far as the digital transition is concerned there seems to be even more disquiet in the public discourse about the risks for the labour market. One of the explanations for the recently documented large decline in the labour share of income in the US (see Karabarbounis and Neyman, 2014) - that is the percentage of national income that accrues to labour - is the ever increasing incorporation of automation, artificial intelligence and digital technologies in the everyday workings of the economy (see Acemoglu and Restrepo, 2018). Two recent highly cited publications (Brynjolfsson and McAfee, 2014; Schwab, 2017) contend that the rapid rise of digital technologies might destroy or displace much more jobs than it creates, echoing the concerns that had already been raised by economists like Keynes (and his concept of `technological unemployment') and Leontief (who was overly pessimistic regarding the negative impact of technological advancements on labor). Another stream of research shows that while automation and digitalization may indeed have an impact on the labour market, this is not necessarily going to be as disruptive (see, for example, Susskind, 2020). In the same vein, in a series of contribution, Acemoglu and Restrepo develop a task-based framework of automation (see, among others, Acemoglu and Restrepo, 2018, 2019, 2020, Acemoglu et al., 2020) in the context of which the net impact of automation largely depends on the interplay of two main effects: the displacement effects, that is, the extent to which capital substitutes for labour, and the productivity effect, that is, whether the productivity gains of automation generate new tasks for labour.[2] Nonetheless, Acemoglu, 2025 shows that the overall impact of AI on total factor productivity is rather modest, being calculated to be less than 1% in the coming decade. Overall, there is no clear consensus regarding the impact that the new wave of digitalization – including AI and automation- will exert on the labour markets and the production structure of the economy; see, e.g. Aghion et al., 2019; Acemoglou and Restrepo, 2018 and

[2] For an overview of the current state of the literature on automation and its economic impact, the interested reader is referred to Restrepo, 2024 and the references therein.

Susskind, 2020. There is, however, little doubt that the effects of the digital transition could be very heterogeneous across Member States and regions (e.g. Santos et al., 2023a; Cicerone et al., 2023).

The literature focusing on the assessment of the potential effects of climate change and the digital transformation on the economic performance of the EU's regions can be broadly split in two large strands: on the one hand, the part of the literature concerned solely with the green transition and on the other hand the literature assessing the impact of the twin transition, namely the digital and green transition. The following Table 1 presents a schematic summary of some of the main contributions. These studies investigate different areas associated with the twin transition and use different proxies and methodologies. They also measure either the readiness or the vulnerability to the twin transitions, depending on the variables that are employed. As is evident from the Table, a lot of emphasis has been placed on the potential effects of the green transition. McDowall et al. (2023), Santos et al. (2023b) and Rodriguez-Pose and Bartalucci (2024) employ composite indicators (based on different aggregation approaches) in order to assess the regional vulnerability to the green transition. Their results, though they differ due to the different variables employed, underscore an overall higher vulnerability in less developed areas in Southern and Eastern Europe. As regards the digital transition, most of the related contributions structure their analysis around the use of data on patents. In this context, patents can be broadly considered as a measure capturing the innovation capabilities of the region. Some authors have opted to split the available patents into `green' and `digital' as a means of studying a particular aspect of the twin transition (see Bello et al., 2023; Damioli et al., 2024; Fazio et al., 2024). These works using patents to measure the readiness aspect highlight a spatial concentration of capacities to transition, mostly along core-periphery lines (Bello et al., 2023; Bachtrögler-Unger et al., 2023), with regions which exhibit a lower innovation capacity likely being the less prepared (Fazio et al., 2024). While not challenging this trend, works employing a broader set of variables, including socio-economic indicators or proxies for green/digital (investment) policies, such as Cappellano et al. (2022) and Maucorps et al. (2023), point to a more nuanced geography of "readiness".

Table 1. Summary of related-literature on measuring regional transition and the vulnerability and readiness to industrial transition

Authors	**What is measured?**	**Which dimension is measured?** (Readiness/ Vulnerability)	**How?** (Variables)	**How?** (Aggregation method)
Bello et al. (2023)	Twin (innovation) transition	Readiness	Patents	Descriptive analysis
Cappellano et al. (2022)	Societal changes: e.g. bioeconomy, climate change, health, innovative society	Readiness	Number of publication per region, number of EU-FP coordinated projects per region, patent applications per region, ERDF and H2020 funding	Linear unweighted, Principal Components Analysis
Damioli et al. (2024)	Twin (innovation) transition	Readiness	`Green' and 'digital' publications obtained via the Web of Science	Econometrics and NLP analysis
Fazio et al. (2024)	Twin (innovation) transition	Readiness	Patents	Spatial data analysis

Continued on the next page...

Table 1. Summary of related-literature on measuring regional transition and the vulnerability and readiness to industrial transition (Continuation)

Authors	**What is measured?**	**Which dimension is measured?** (Readiness/ Vulnerability)	**How?** (Variables)	**How?** (Aggregation method)
Maucorps et al. (2023)	Twin transition	Readiness	GDP (level and growth), Labour productivity, Business Sophistication, Emissions, RCI sub-indices (infrastructure, innovation, labour market efficiency)	Average of z-scores
Bachtrögler-Unger et al. (2023)	Twin Transition	Readiness	Patents	Descriptive analysis
McDowall et al. (2023)	Green (energy) transition	Vulnerability, Readiness	Unemployment, Innovation Potential (RIS), Employment	Geometric
Rodríguez-Pose and Bartalucci (2024)	Green transition	Vulnerability	GVA and Employment of Agriculture, Wages and Salaries in Mining and Quarrying, CO_2 emissions	Principal Components Analysis
Santos et al. (2023)	Environmental sustainability	Vulnerability	Wages and salaries, emissions	Additive
Vrontisi et al. (2022)	Green (energy) transition	Vulnerability, Readiness	GDP per capita, Unemployment, Investment per capita, RCI indices	Geometric

Source: Own elaboration based on the cited studies.

3. Data and methods

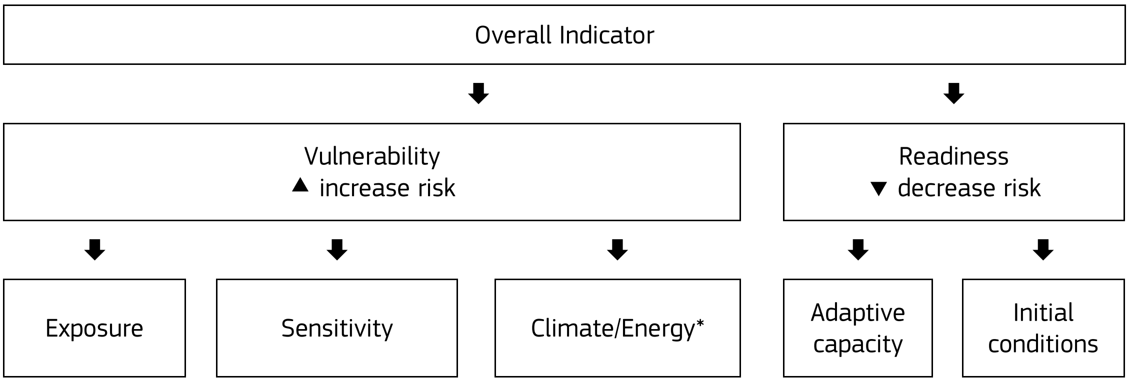
To obtain insights into the potential effects of the ongoing green and digital transition processes are going to exert on the EU NUTS2 regions, we need an empirical measure that can capture the various anticipated effects to the greatest possible extent. An important caveat of our empirical approach is related to data availability; given that our unit of analysis is the EU NUTS2 level, a number of variables that could be utilized as proxies are not available at this level of disaggregation thus limiting the number of available proxies. This implies that our indicator is not able to capture – to the extent that we would like - certain aspects of the regional economic structure and its relations to the transition process. Indicatively, due to the lack of disaggregated data on the various investment assets (e.g. dwellings, research and development, software and databases etc.) we cannot adequately capture the importance of the various types of investment in terms of a region's readiness to tackle the challenges of the transition process.

In this section, we first describe the dimensions of the proposed indicator along with the data that were utilized as their proxies and then proceed with presenting the approach followed for the construction of the composite indicator. Our empirical approach is similar to the one of McDowall et al. (2023), who focus on assessing the impact of the energy transition in certain sectors of economic activity.

3.1. Dimensions of the indicator

As already mentioned in the introduction, the aim of this paper is to develop a composite indicator that is able to capture two important dimensions related to the process of the green and the digital transition, namely, vulnerability and readiness, as summarized in Figure 1.

Figure 1. Structure of the indicator



Source: Authors´ own elaboration

*Note: * Only applies to the "Green transition" index.*

In the context of this paper, we draw inspiration from the risk concept of the JRC Risk Data Hub, according to which risk is defined as a combination of exposure, hazard and vulnerability. In this paper, we focus on vulnerability as the core concept. In particular, vulnerability is broadly understood as being related to the risks that the regions are likely to face during the transition period. In particular, similar to McDowal et al. (2023), the notion of vulnerability is conceptualized as encompassing three dimensions: exposure, sensitivity and climate and energy risk.

• The exposure to risk captures essentially the direct effects that the ongoing transition is going to exert across the EU regions. In particular, from an economic point of view, in this paper exposure to risk is associated with the level of employment, for example, in the most polluting sectors across regions in the case of the green transition indicator (a similar approach was followed by Vandeplas et al., 2022 and Vona et al., 2018). [3] If the target of reaching net-zero emissions is to be attained, employment in the `brown' sectors, i.e. the sectors that are producing the largest amounts of emissions, is more likely to be at risk. Of course, this approach is not able to capture the potential indirect effects (or, spillovers) on employment in sectors that are linked with the `brown' ones. In that sense, our indicator is able to provide us with a lower bound of the risk associated with the displacement of jobs during the implementation of the measures related to the transition. Based on a similar argument, for the digital transition dimension, our proxy for exposure will be the level of employment in the sectors that are characterized as the ones least using information and communication technologies (ICT). In particular, we use the taxonomy developed by the OECD in Calvino et al. (2018), which classifies the sectors of economic activity based on how far they have come in terms of the digital transformation. Despite some drawbacks (e.g. the taxonomy cannot fully account for frontier technologies such as machine learning) it provides a useful benchmark for the analysis of the effects of further digitalization. In particular, our hypothesis is that sectors which are relatively less digitalized are more likely the bear the largest impact in terms of employment, as they may be subject to a higher risk of seeing the tasks related to these sectors being made redundant or the relevant jobs being displaced. It is worth noting here that the sectors identified on the basis of the OECD taxonomy are broadly similar with to the sectors identified as more vulnerable to the digital transition in, for example, Cirillo et al. (2021) – see also the Mckinsey Global Institute (2017) report.

• The region's sensitivity to the transition process embodies the extent to which the region is likely to be affected by the transition process. Specifically, from an economic point of view, sensitivity is directly related with the loss of jobs due to the changes in the structure of the regional economy that are expected to accompany the transition. Based on this argument, our proxy for sensitivity will be the level of regional unemployment. A region that was already experiencing relatively high (and, potentially, persistent) unemployment rates is more likely to suffer even further job losses. This is due to the fact that when the labour market is characterized by the presence of slack (i.e. a high unemployment rate) a negative shock is more likely to further lower labour demand, leading to further increases in unemployment. As expected, vulnerability is assumed to be a positive function of both dimensions, that is, if either exposure or sensitivity increase, the vulnerability to which the region is exposed to will be higher.

• The climate and energy risk component aims to incorporate the heterogeneous impact exerted by the changes in the energy (and, in particular, electricity) prices faced by final consumers and the climatic conditions. Specifically, the aim of the green transition, that is the reduction of the greenhouse gas emissions, may ultimately lead to higher inflation rates (at least, in the short-run). These increases in the price level are, partly, caused by a phenomenon dubbed as `greenflation' in a recent speech by I. Schnabel (2022). Specifically, this shock is related to the fact that the success of the green transition hinges upon large increases in the level of investment in order to achieve a change in the production processes that will lead to reduced emissions. This raises an interesting

[3] For the list of the most polluting sectors and the approach utilized for their identification, see the accompanying Appendix.

paradox, in that "…the faster and more urgent the shift to a greener economy becomes, the more expensive it may get in the short-run" (Schnabel, 2022). [4] To an extent, these increases in the energy-related prices may fuel an increase in in the negative sentiments of citizens toward the ongoing green transition thus raising the discontent toward the green transition put forward –see Rodriguez-Pose and Bartalucci (2024).

Another source of increased risk is the deterioration of the climatic conditions –proxied via the number of cooling and heating degree days. [5] This deterioration may lead to increases in the demand for electricity (i.e. to increases in energy consumption) as for example households require more electricity in order to heat (cool) their dwelling with cooling (heating) days. This increased demand for electricity, when the prices with which consumers are faced are already high, will likely lead to even further price increases.

The second component of the indicator, namely, readiness is associated with two important aspects of the regional economies' structure. Firstly, their ability to adapt to the changes brought about by secular processes – like the green and the digital transitions - and absorb the impacts caused by them. [6] Secondly, the initial conditions that characterize the state of the economy at this particular point in time. As such, they are associated with the current state of the region's overall structure, ranging from its relative position in the income distribution to factors related to competitiveness and technological and innovation capabilities. These sub-dimensions are defined as follows:

• The adaptive capabilities of a region: apart from the more idiosyncratic characteristics, there are two factors which are important for both dimensions of the ongoing industrial transition: the private investment share and human capital. Intuitively, a high private investment share points to a region that has adequate infrastructure and can mobilize funds when necessary in order to boost economic activity and cover the investment gaps arising during the transformation process. In the same vein, higher levels of human capital indicate that the region has invested in developing the skills of its citizens via education (or, it managed to attract high-skilled labour in the region). Regions equipped with human capital can better adapt to changing economic circumstances. In a recent contribution, Brey and van der Marel (2024) show that human capital is one of the main factors explaining the adoption of AI across the EU. Turning to the more idiosyncratic factors, for the green transition we consider as an additional important factor the size of cohesion policy funds that were earmarked for green projects during the 2014-2020 programming period. Our reasoning is that these amounts were at the disposal of the region to facilitate green investment projects, irrespective of the prevailing economic conditions. That is, unlike other investment plans that were curtailed due to the economy finding itself at the bust phase of the cycle, cohesion funds ensured that approved projects could continue. Moreover, we will include the share of green patents as a means of capturing a different dimension of the regional technological and innovation capabilities that shape the region's ability to adapt. As regards the digital transition, we propose to include the

[4] Of course, this is not the only reason behind the potential increases in the price level. Lastly, it should be noted that the green transition takes place alongside a number of policies designed to reduce emissions, like carbon pricing and ETS. These could also lead to inflationary pressures – see, for example, Bettarelli et al. (2025).

[5] Cooling (CDD) and Heating (HDD) degree days are weather-based technical indices designed to describe the energy requirements of buildings in terms of heating or cooling.

[6] Of course, this notion of adaptive capacity encompasses the region's ability to adjust and recover from shocks of (macro)economic nature that are either caused by or coincide with the ongoing transition.

share of cohesion funds allocated to digital projects; the reasoning behind our choice follows from the same argument as in the case of the green transition.

• The initial conditions characterizing a region: a factor that is common for both the green and the digital transition is the level of per capita GDP. We posit that richer regions have significantly more resources at their disposal to use in order, for example, to initiate big investment projects and attract the human capital necessary for meeting the targets of the transition and ensuring that their citizens are –at a minimum- not made worse off. Additionally, we will use the Regional Innovation Index produced by the European Commission as a proxy of the innovation capabilities of a region. A region that is classified in the lower end of the innovation distribution is in a relatively worse position, as it will need to mobilize more funds in order to improve its capabilities, making it more difficult to implement, in a timely manner, the changes necessary for a successful transition. Turning to factors specific to the green transition, we propose the use of the (long-run) rate of change in emissions. This proxy, also employed by Rodriguez-Pose and Bartalucci (2024) shows whether a region had already managed to decrease its level of emissions, positioning it in a relatively better off state compared to a region that hadn't managed to do so. As regards the digital transition, we will additionally use the business sophistication sub-index of the European Commission's Regional Competitiveness Index. This index captures the potential for specialization and diversification in a region and, as such, can serve as a proxy highlighting the fact that some regions are better placed to take up and make use of digital technologies.

3.2. Data sources

The data that have been utilized to serve as the proxies of the dimensions mentioned above, along with their sources, are summarized in the following Table 2. Additional information regarding all the variables employed in the analysis can be found in the accompanying Appendix.

Table 2. Variables included in the Green and digital transition indicators

Dimension	Data	Source
Green transition		
(a) Vulnerabilities		
Exposure	• Employment rate in `brown' sectors	Authors' calculation based on Eurostat [env_ac_aeint_r2] and Kostarakos and Marques Santos (2024)
	• Emissions per capita	ARDECO [EDGARP]
Sensitivity	• Regional unemployment	ARDECO [RNUTN]
Climate and Energy	• Cooling and heating degree days	Eurostat [nrg_chddr2_a]
	• Household electricity prices	Eurostat [nrg_pc_204]
	• Non-household electricity prices	Eurostat [nrg_pc_205]
(b) Readiness		
Adaptive capacity	• Human Capital index based on educational attainment	Authors' calculation based on Eurostat [edat_lfse_04]
	• Private sector investment rate (excludes investment in sectors O, P and Q)	Authors' calculation based on ARDECO [ROIGZ]
	• Green cohesion expenditures	Authors' calculation based on Kohesio data
	• Green patents	Authors' calculation based on KNOWMAK

Continued on the next page…

Table 2. Variables included in the Green and digital transition indicators (Continuation)

Dimension	Data	Source
Green transition		
(b) Readiness		
Initial conditions	• GDP per capita	ARDECO [SOVGDP]
	• Change in CO2 emissions, 1990 to 2019	Authors' calculation based on ARDECO [EDGAR]
	• Regional innovation index	Regional Innovation Scoreboard
Digital transition		
(a) Vulnerabilities		
Exposure	• Employment rate in the least ICT using sectors	Authors' calculations based on OECD (2018)
Sensitivity	• Regional unemployment	ARDECO [RNUTN]
(b) Readiness		
Adaptive capacity	• Human Capital index based on educational attainment	Authors' calculation based on Eurostat [edat_lfse_04]
	• Private sector investment rate (excludes investment in sectors O, P and Q)	Authors' calculation based on ARDECO [ROIGZ]
	• Digital cohesion expenditures	Authors' calculation based on Kohesio data
Initial conditions	• GDP per capita	ARDECO [SOVGDP]
	• Business sophistication	Regional Competitiveness Index
	• Regional innovation index	Regional Innovation Scoreboard

Source: Own elaboration based on the cited studies.

Note: To identify green and digital cohesion expenditures, we use text-mining techniques to project and title description.

3.3. Aggregation Method

In order to construct the proposed composite indicator, a number of steps are necessary. In particular, all the relevant data need to be normalized and then aggregated to the various sub-indices with the appropriate choice of the weighting scheme, prior to the calculation of the final index. Some additional statistical analysis, following the 10 steps guide of the European Commission's JRC Competence Centre on Composite Indicators and Scoreboards (see JRC-COIN, 2020) pertaining to the analysis for the presence of outliers, collinearities etc. is presented in the Appendix.

The first step in computing the aggregate composite indicator consists of normalizing the variables of interest. In this paper, we implement the Min-Max transformation (used, among others, in the European Commission's Regional Innovation Index). In particular, for any given variable x the normalization is based on the following equation (1):

$$x_{norm} = \frac{x - x_{min}}{x_{max-}x_{min}} \quad (1)$$

where x_{max} and x_{min} denote the maximum and the minimum value of x for any region. By definition, the normalized variable now lies in the interval [0,1]. As such, all the components of the indicator now have a very intuitive interpretation: they depict the relative performance of each of the EU regions.

Having normalized all the variables of interest, we proceed with aggregating them into our composite indicator. Our method of choice is that of the geometric aggregation, based on which the indicator takes the following multiplicative form:

$$Index_r^j = Vulnerability_r^{w_v} * (1 - Readiness)_r^{w_R} \tag{2}$$

where:

$$Vulnerability_r = Exposure_r^{w_E} * Sensitivity_r^{w_S} * ClimateEnergy_r^{w_{CE}} \tag{3}$$

$$Readiness_r = Adaptive\ Capacity_r^{w_{AC}} * Initial\ Conditions_r^{w_{IC}} \tag{4}$$

where r denotes the region, j denotes the dimension of the transition under examination (i.e. green or digital) and w_i denotes the weights assigned to each of the components (for example, w_v, w_R denote the weights assigned to the vulnerability and the readiness components, respectively). We note here that, in each equation, the weights sum to unity. Additionally, when a dimension of the indicator has more than one components (e.g. the adaptive capacity or the initial conditions dimensions), the aggregation principle remains the same. That is, each of the components carries its own weight, the sum of the weights is unity, and they enter each dimension multiplicatively.

Equation (2) depicts the overall index related to the challenges accompanying the transition, summarizing the combined effects of the two dimensions, namely vulnerability and readiness. As is evident from the equation, increases in vulnerability are associated with an increase in the overall index, while higher levels of readiness counteract these negative effects. Equations (3) and (4) exhibit the two dimensions of the index, namely the component related to vulnerability, which depends on the region's exposure to risk and its sensitivity to changes in the economic environment, and the component accounting for the region's readiness, which is determined by the adaptive capacity capabilities and the initial conditions characterizing the region. We note here that in the case of the "Green Transition" index only, vulnerability also depends on the Climate/Energy component analysed above.

The multiplicative form of the indicator has two important advantages. Firstly, in contrast to the additive approach usually employed, it can account for the distortionary impact of full compensability (for more details see chapter 6 of the OECD (2008) manual). Put simply, if the various components of the indicator were to be aggregated in an additive manner, then it is possible that very large in magnitude values across some of the components could fully offset the impact of very low in magnitude values. Especially in the context of assessing the overall risk stemming from the transition process, it is preferable that only some degree of compensability is allowed for, as this facilitates a clearer exposition of the trade-offs involved. In order to highlight this point, consider the following extreme scenario: a region in which the degree of readiness is equal to one. In this case, under an additive aggregation scheme, this region –despite exhibiting the highest possible degree of adaptive capacity and optimal initial conditions- would still face a (potentially non-negligible) level of risk. On the contrary, under the geometric aggregation scheme, this region would face zero risks from the transition process, as it would have the capacity to fully offset the associated negative effects.

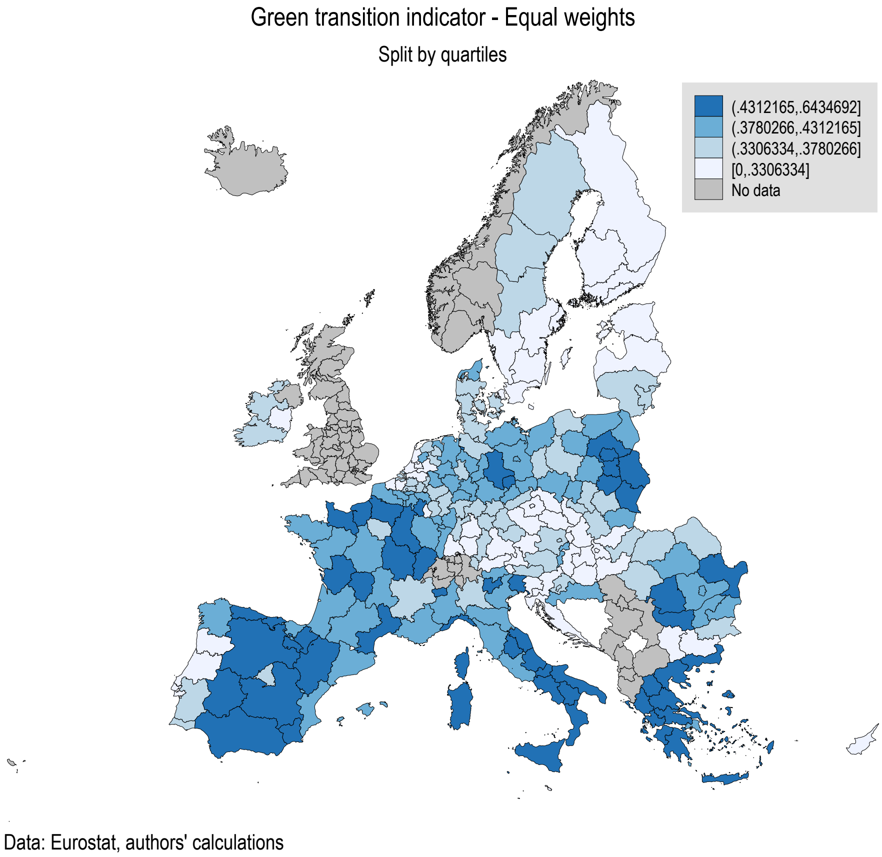
Secondly, under this approach, the resulting indicator exhibits a significant degree of flexibility. In particular, the weights -w- included in equations (2) to (4) are not predetermined. Rather, one can think of alternative weighting schemes that allow for the investigation of various scenarios reflecting the preferences, in terms of trade-offs, of the researcher and/or the policymaker. In this paper, we chose as a benchmark the equal weights set in which every component of the indicator is assigned the same weight (for example, when only two components are involved, then $w_i = 0.5$). Under this weighting scheme, all the components of the indicator carry the same importance for the policymaker, which can serve as a useful benchmark for a more in depth analysis of the potential trade-offs.

In order to assess the robustness of our results and obtain further insights into the sensitivity of the aggregate indicator to different assumptions regarding the weights, we also explored two alternative weight schemes; specifically, we choose a set of weights that places greater emphasis on the vulnerability component in which $w_v = 0.75$, while we also experimented with a scenario in which readiness can more than compensate the vulnerability risks imposed (i.e. we assume that $w_R = 0.75$).

4. Results

The resulting indicator is presented in Figure 2 and Figure 3, which depict the quartile distribution of the overall indices for the green and the digital transition, respectively, across the EU NUTS2 regions for the year 2019. As can be gleaned from the Figures, a number of interesting facts and spatial patterns seem to arise. Starting with the green transition indicator in Figure 2, we observe that the highest magnitudes of the indicator –which translate into higher risk with respect to the transition- are mainly located in the southern periphery of the EU and in regions within Central and Eastern European (CEE) countries. Among more advanced economies, various regions in the Nordic countries as well as Eastern Germany ones appear also to be facing a relatively high risk. Conversely, some Eastern and Central countries, such as Slovenia, Slovakia, Czechia or the Baltics show a lower risk. Overall, the indicator exhibits clear core-periphery patterns, with a concentration of regions with high readiness and less vulnerability in capital regions and part of the "Blue Banana". This essentially confirms that the lowest risk is located in the wealthiest area of the continent.

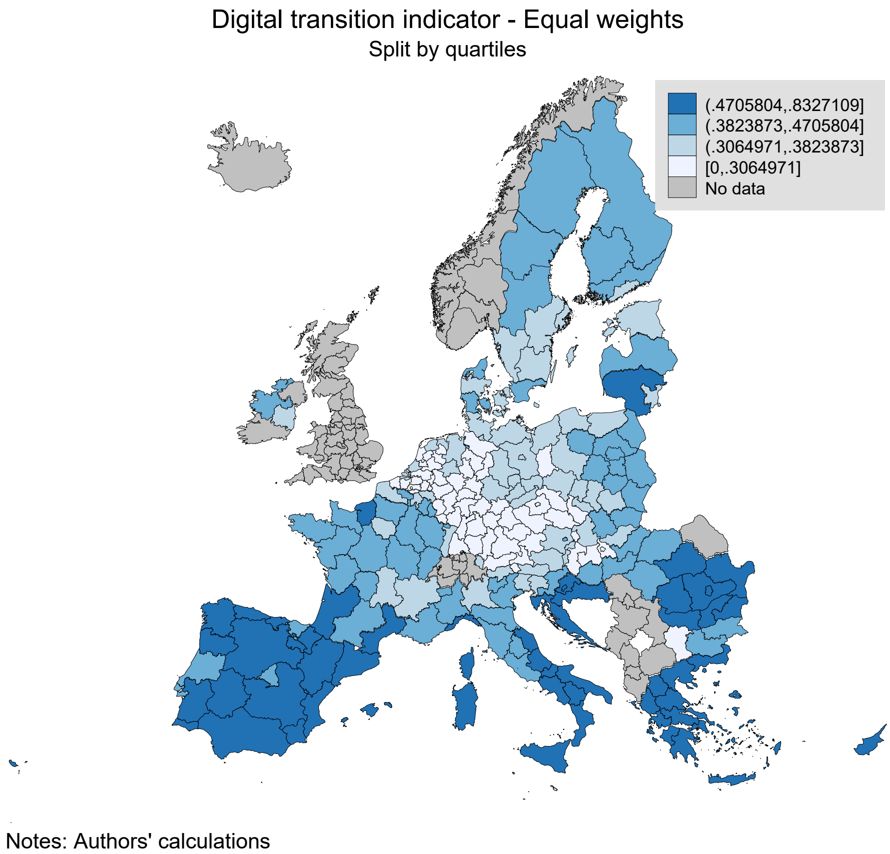
Figure 2. Green transition index for the EU NUTS2 regions



Source: Authors' calculation

A similar picture emerges with respect to the risk associated with the digital transition, which is depicted in the map of Figure 3. Here, it is evident that the regions in the southern periphery of Europe exhibit the largest in magnitude risk-related indicators, with the sole exceptions being the capital regions. Again, these are regions that have the lowest ranking in terms of the readiness component. The regions with the least vulnerability and highest readiness appear even more geographically concentrated in an area covering Germany, Benelux, Austria, and Czechia. Overall, more regions appear to face a higher risk than for the green indicator.

Figure 3. Digital transition index for the EU NUTS2 regions



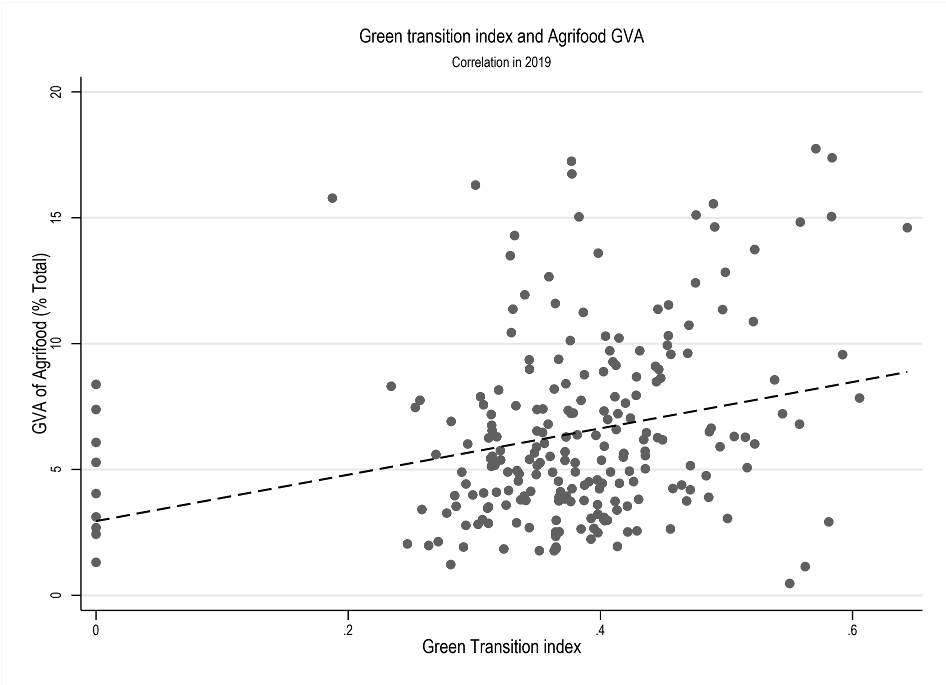
Source: Authors' calculation.

These observations suggest that significant levels of investment are necessary for these regions to be able to improve their technological and innovation capacities in order to address any shortcomings in terms of achieving a higher degree of digitalization.

To further investigate the relationship between the proposed overall indicators and the structure of the EU's regional economies, we make use of the notion of industrial ecosystems as developed by the European Commission. Briefly, the notion of the industrial ecosystems was developed as a means of encompassing the interrelations, interdependencies and the interconnectedness of the various sectors of economic activity. Specifically, an ecosystem is defined as the weighted sum of various sectors of economic activity (based on the NACE Rev.2 classification) which are deemed to show strong interconnectedness. Out of the 14 ecosystems identified by the European Commission (2021), the ones relevant for the purposes of this paper are the Agrifood and the Digital ecosystems, which are directly related to the subject matter of the twin transition. Figures 4 and 5 plot the relationship of the risk indicators and the Gross Value Added (GVA) of the two ecosystems.

As is evident from Figure 4, there exists a positive correlation between the green transition index and the relative importance of the Agrifood ecosystem. In particular, the higher the share of the Agrifood ecosystem in regional GVA, the higher the associated risk. This correlation is anticipated, as the Agrifood ecosystem encompasses sectors that are significant contributors in terms of emissions, implying that the regions which exhibit a big reliance on Agrifood will need to undergo a significant transformation process in order to reduce their emissions, which will likely put the jobs of this ecosystem in danger of being displaced or, even, lost.

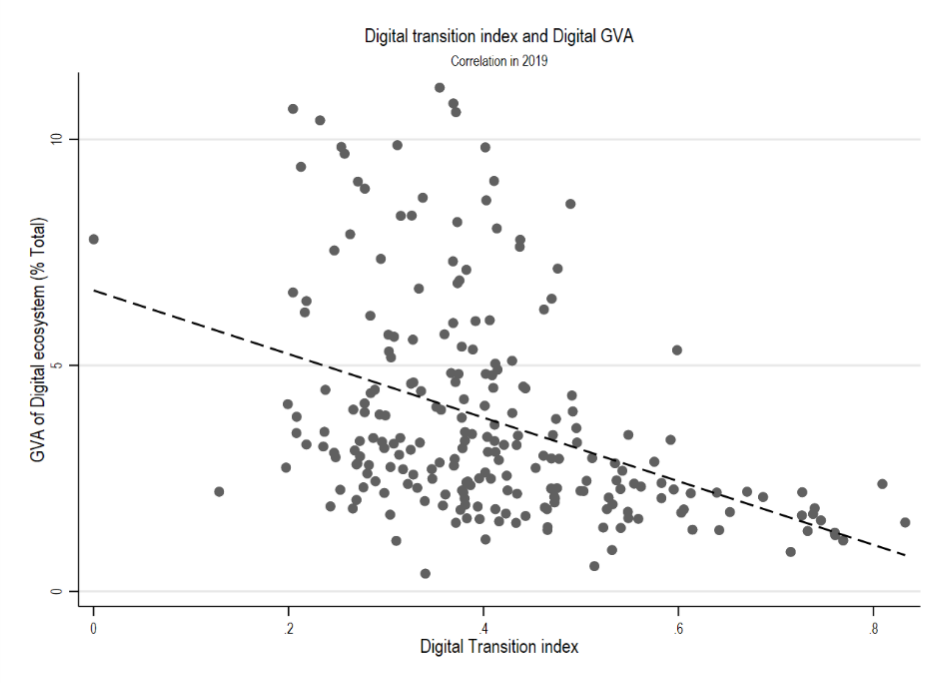
Figure 4. Correlation between green transition index and Agrifood ecosystem's GVA share



Source: Authors' calculation

On the contrary, regions that have already transformed their structure into being more digital, as captured by the relative importance of the Digital ecosystem in terms of GVA production, are in a better position to tackle the risks associated with the digital transition. As can be gleaned from Figure 5, the lower the importance of the Digital ecosystem, the higher the magnitude of the digital transition index. This implies that the less digitized regions are in need of further investment, in terms of both physical and human capital, in order to boost their technological and innovation capabilities as a means of attenuating the risks of the digital transition.

Figure 5. Correlation between green transition index and Digital ecosystem's GVA share

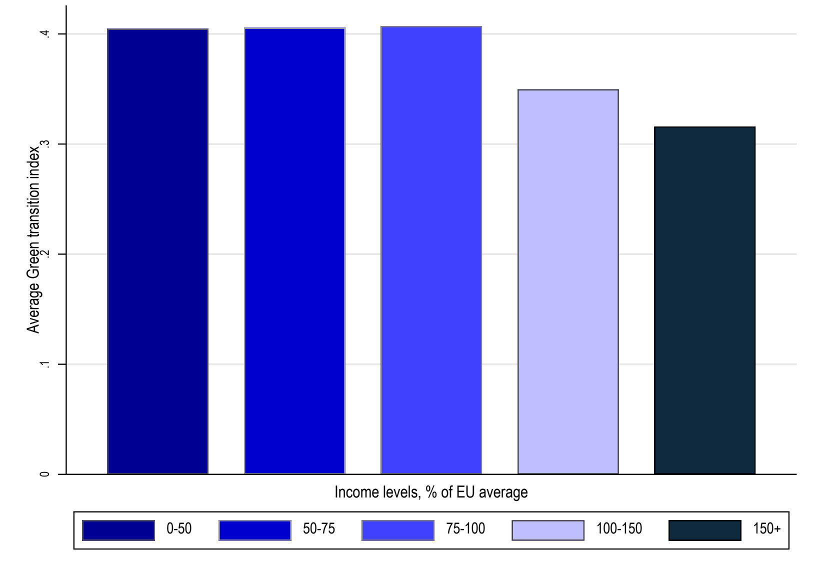


Source: Authors' calculation

4.1 The importance of regional relative income

Another important aspect of the relationship between the proposed risk indicator and the current state of the EU's regional economies concerns the relative income level of the regions. In particular, it is important to explore whether there exists a negative correlation between income and risk, that is, whether richer (poorer) regions face lower (higher) risks with respect to the ongoing transition process. In Figures 6 and 7 we present the average scores of the two transition risk indices across the regional income distribution. In particular, regions are split across five income groups based on their GDP per capita for 2019 relative to the EU27 average. As is evident from the Figures, the relative position of the region is negatively correlated with the size of the transition indices. That is, the higher the region is placed in terms of its GDP per capita with respect to the EU27 average, the lower the overall risk associated with the transition. To be more specific, the results contained in Figure 6 indicate that the risks associated with the green transition are higher at the lower end of the income distribution and, in particular, for those regions that exhibit a level of GDP per capita that is lower than 75% of the EU average – the so-called `less developed' regions according to the European Commission's cohesion classification criteria. Interestingly, the regions in transition (those with a level of GDP per capita that is between 75% and 100% of the EU average) also exhibit high relative risk. The richer the region is, the lower the green transition risk as captured by the proposed indicator appears to be, with the `more developed' regions –that is, regions with a level of GDP per capita more than 100% of the EU average– exhibiting a significant decrease in terms of the magnitude of the indicator.

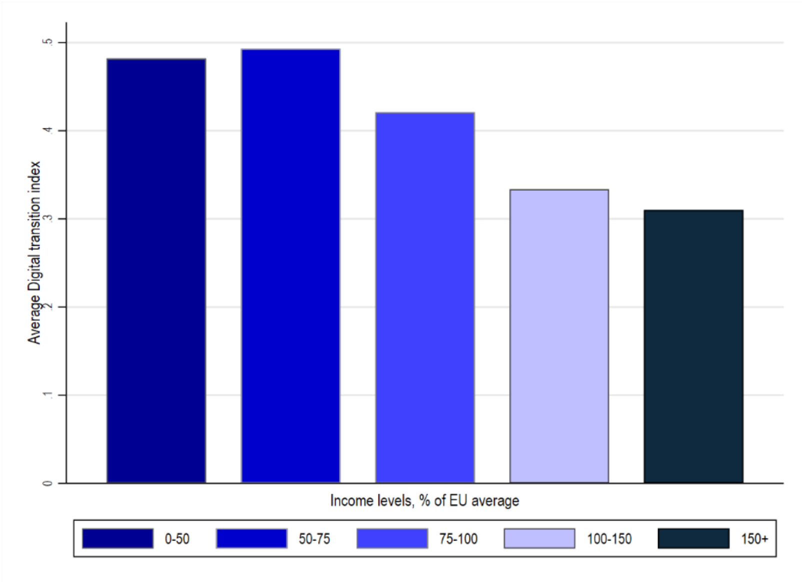
Figure 6. Average green transition index values by income group



Source: Authors' calculation

This negative relationship between the risk indicator and the income level is even more pronounced when the digital transition case is examined. In particular, as is evident from Figure 7, the risk associated with the digital transition is at its highest in the less developed regions and although it exhibits a decline in the case of the transition regions (i.e. those regions whose GDP per capital lies between 75 and 100% of the EU average), the marked decrease in the magnitude of the indicator only occurs in the case of the more developed regions.

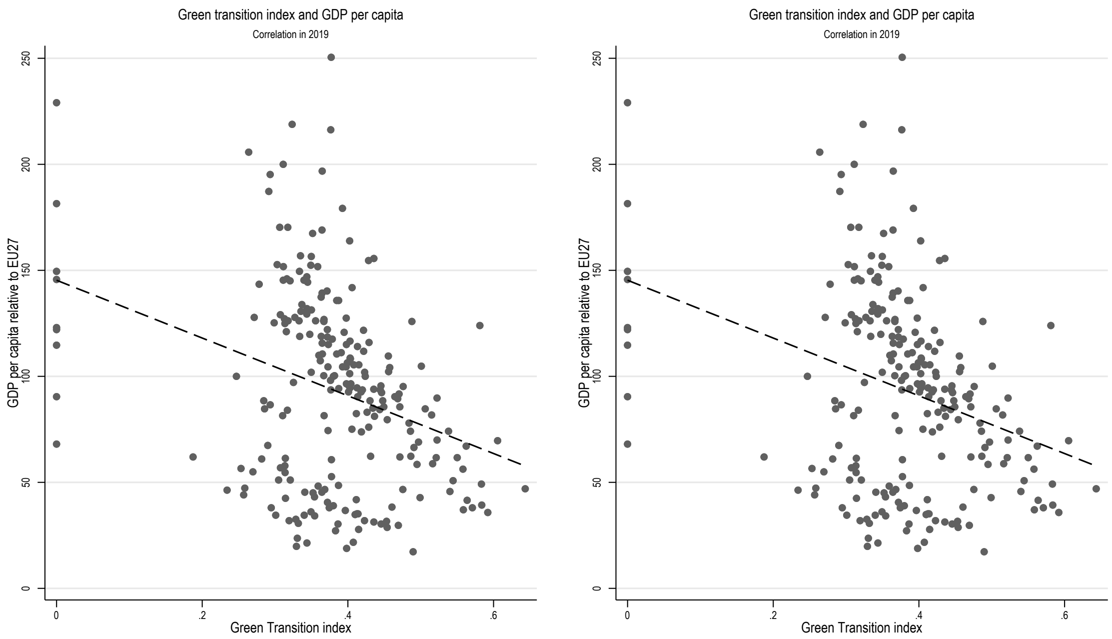
Figure 7. Average digital transition index values by income group



Source: Authors' calculation

We further assess this relationship by plotting regional GDP per capita (as a share of the EU average) against the two risk indicators. As is evident from Figure 8, there emerges a rather strong negative relationship between the relative income position of a region and the overall risk indices. That is, relatively poorer (or, lagging-behind) regions, especially those below the 75% income threshold, exhibit higher values in both the green and the digital transition risk indices. Our results are in full accordance with the findings of Rodriguez-Pose and Bartalucci (2024) who examine the vulnerability of the EU regions with respect to the green transition.

Figure 8. Relationship between GDP per capita and the transition risk indices



Source: Authors' calculation

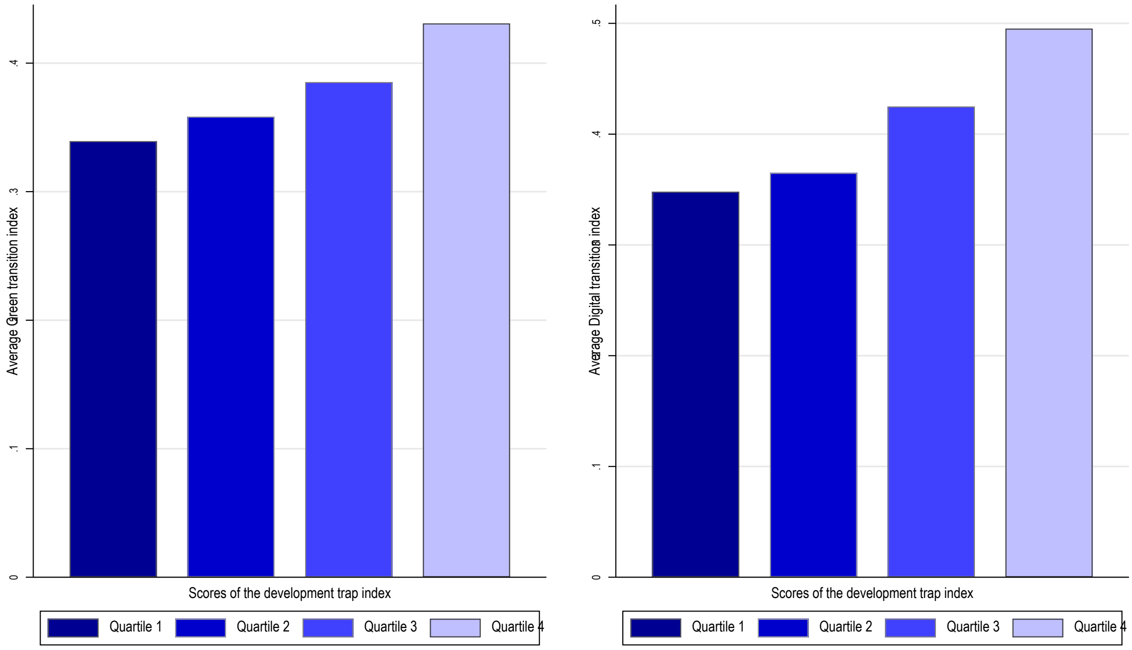
Note: For better exposition of the results, in each of the two panels the observations that were identified as being outliers (that is, observations which attain extreme values of either relative GDP per capita and the respective index) are excluded. The inclusion of these observations does not affect the overall strong negative correlation result.

Overall, the results of the extensive descriptive analysis presented in this section seem to point towards the conclusion that –among others- the relative income position of the EU's regional economies is strongly negatively correlated with a higher risk stemming from both the green and the digital transition. The less-developed regions, according to the cohesion criteria, are the ones more exposed to the vulnerabilities accompanying the transition. The analysis clearly highlights the significant heterogeneity of the risks anticipated along the transition path, pointing towards a source of discontent as clearly illustrated in Rodriguez-Pose and Bartalucci (2024).

4.2 The relationships between the transition and the development trap

As a means of further examining the characteristics that shape the relative stance of regions in terms of the ongoing transition, in this section we focus on the relationship between our indices and the economic dynamism of the regions. In particular, we make use of the `development trap' concept developed by Diemer et al. (2022), which essentially posits that the EU regions are facing structural challenges in their attempts to improve the prosperity of their citizens. In particular, the authors claim that (some of) the EU's regions are not able to recover their past good performance across a number of economic dimensions and remain stuck in a development trap. In this context, the development trap indicator can be interpreted as a measure of economic stagnation. For the purposes of this paper, we will make use of the first measure of risk of being development trapped, labelled as DT1 by Diemer et al. (2022).

Figure 9. Relationship between economic stagnation and the transition risk indices



Source: Authors' calculation

Figure 9 plots the average scores of the green and the digital transition risk indices, respectively, against the development trap index scores split by quartile. Each quartile represents the relative level of risk, that is, quartile 1 (the lower 25% of the values of the development trap index) corresponds to low risk, the second quartile to mid-low risk, the third quartile to mid-high and the fourth quartile (the top-25% of the values of the Development Trap index) to high-risk of economic stagnation. As is evident from the Figure, regions with lower scores in the vulnerability index face significantly lower levels of risk with respect to the transition process. In particular, regions which exhibit either a low or mid-low risk of falling in a development trap are associated with lower vulnerabilities and a lower overall risk with respect to the green and the digital transition. On the contrary, regions which face mid-high or high risk of falling in a development trap and facing economic stagnation exhibit larger magnitudes of the green and the digital transition indices and, as such, are more vulnerable to the risks associated with the transition process. In particular, as regards the green transition, the group of regions facing the highest risks of economic stagnation and the risk with respect to both aspects of the transition encompasses Greek regions in the centre and the north of the country, regions in the Northeast of France, in the south of Italy and Sardinia and the Spanish regions of Andalusia and Valencia. These regions emerge as the ones that will face the need to not only overcome the transition-related risks, but also ensure that they manage to escape falling in a prolonged period of economic stagnation.

4.3 Robustness of the results

As a means of assessing the robustness of the estimates presented in the previous section, we also examined the alternative weighting schemes already mentioned. In particular, we examined the case were greater emphasis is placed on the vulnerability aspect (in which the respective weights are $w_v = 0.75, w_R = 0.25$) and the case where readiness is the dimension of higher relative importance (where the respective weights are $w_v = 0.25, w_R = 0.75$). We report here that the qualitative nature of our results remains broadly the same.

5. Conclusions

Ensuring the achievement of a climate-neutral and digitalized economy is one of the EU's primary policy concerns. To this end, the European Commission has launched a number of policy initiatives to help the regions to successfully complete the transition.

Nonetheless, this process is associated with risks related to the current state of the labour market, among other factors. In this context, the aim of this paper was to develop a composite indicator for assessing the risks associated with the green and digital transition processes.

Our analysis shows that the potential effects of the green and the digital transitions are heterogeneously distributed across the EU's regions. In particular, the regions in the southern periphery of the EU are the most vulnerable to the transition, while those in the north are far more prepared to adapt to the new, emerging production process.

Additionally, we demonstrated that the relative income position of the regions is an important factor in determining the risk associated with the twin transition. Less developed, lagging regions (and, to a lesser extent, transition regions) exhibit the highest risk. Lastly, vulnerability to the transition process was shown to be correlated with the probability of falling into a development trap, that is, with the probability of entering a period of economic stagnation.

The results of our analysis point to a case where the ongoing twin transition will generate winners and losers, potentially leading to an increased degree of discontent amongst the regions that are not able to swiftly adapt to the new economic paradigm and reap the benefits of the transition.

Analysis of empirical estimates suggests that successful transitions are associated with increased investment in physical and human capital which boost the technological and innovation capabilities in regional economies. This will most likely mitigate the risks associated with the transition processes and help to minimise the rise in regional (social and economic) discontent.

References

Acemoglu, D. (2025). The Simple Macroeconomics of AI. *Economic Policy,* 40(121), 13-58

Acemoglu, D.& Restrepo, P. (2018). The Race between Man and Machine: Implications of Technology for Growth, Factor Shares and Employment. *American Economic Review*, 108(6), 1488-1542

Acemoglu, D.& Restrepo, P. (2019). Automation and New Tasks: How Technology Displaces and Reinstates Labor. *Journal of Economic Perspectives*, 33(2), 3-30

Acemoglu, D.& Restrepo, P. (2020). Robots and Jobs: Evidence from U.S. Labor Markets. *Journal of Political Economy*, 128(6), 2188-2242

Acemoglu, D.& Restrepo, P. (2022). Tasks, Automation and the Rise in U.S Wage Inequality. *Econometrica*, 90(5), 1973-2016

Acemoglu, D., Lelarge, C. & Restrepo, P. (2020). Competing with Robots: Firm-Level Evidence from France. *AEA Papers and Proceedings*, 110, 383-388

Aghion, P., Antonin, C., & Bunel, S. (2019). Artificial intelligence, growth and employment: The role of policy. *Economie et Statistique/Economics and Statistics*, (510-511-512), 150-164.

Bachtrögler-Unger, J., Balland, P. A., Boschma, R. and Schwab, T. (2023). Technological capabilities and the twin transition in Europe: Opportunities for regional collaboration and economic cohesion. *MPRA Paper 117485, University Library of Munich, Germany.*

Bello, M., Castellani, D., Damioli, G., Marin, G. and Montresor, S., The geography of EU green and digital inventions and their knowledge sources, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/669328, JRC133565.

Bergant, K., Mano, R., & Shibata, M. I. (2022*). From polluting to green jobs: a seamless transition in the US?*. International Monetary Fund.

Bettarelli, L., Furceri, D., Pisano, L & Pizzuto, P. (2025), Greenflation: Empirical evidence using macro, regional and sectoral data, *European Economic Review*, 174

Brey, B & van der Maler, E (2024). "The Role of Human-capital in Artificial Intelligence Adoption", *Economics Letters,* https://doi.org/10.1016/j.econlet.2024.111949

Brynjolfsson, E., and McAfee, A. (2014). The second machine age: Work, progress, and prosperity in a time of brilliant technologies. W W Norton & Co.

Calvino, F., C. Criscuolo, L. Marcolin and M. Squicciarini (2018). "A taxonomy of digital intensive sectors", OECD Science, Technology and Industry Working Papers, No. 2018/14, OECD Publishing, Paris. DOI: 10.1787/f404736a- en.

Cappellano, F., Makkonen, T., Dotti, N. F., Morisson, A. & Rizzo, A. (2022) Where innovation meets directionality: an index to measure regional readiness to deal with societal challenges, *European Planning Studies*, 30:8, 1549-1576, DOI: 10.1080/09654313.2021.1976114

Cicerone, G., Faggian, A., Montresor, S., & Rentocchini, F. (2023). Regional artificial intelligence and the geography of environmental technologies: does local AI knowledge help regional green-tech specialization?. Regional Studies, 57(2), 330-343.

Cirillo, V., Evangelista, R., Guarascio, D., & Sostero, M. (2021). "Digitalization, routineness and employment: An exploration on Italian task-based data", *Research Policy*, 50(7), 104079.

Damioli, G.; Bianchini, S. & Ghisetti, C. (2024): The emergence of a 'twin transition' scientific knowledge base in the European regions, *Regional Studies*, DOI: 10.1080/00343404.2024.2355998

Diemer, A., Iammarino, S., Rodríguez-Pose, A., & Storper, M. (2022). The Regional Development Trap in Europe. Economic Geography, 98(5), 487–509.

European Commission (2021). Annual single market report 2021 – SWD (2021) 351 final. Technical report, European Commission.

European Commission (2022). *8th Report on Economic, Social and Territorial Cohesion: Cohesion in Europe towards 2050*. Luxembourg: Publications Office of the European Union.

European Commission: Directorate-General for Regional and Urban Policy, *Forging a sustainable future together – Cohesion for a competitive and inclusive Europe – Report of the High-Level Group on the Future of Cohesion Policy,* February 2024, Publications Office of the European Union, 2024, https://data.europa.eu/doi/10.2776/974536

European Commission: Directorate-General Joint Research Centre, (2020): "10 Step Pocket Guide to Composite Indicators & Scoreboards" available at https://knowledge4policy.ec.europa.eu/sites/default/files/10-step-pocket-guide-to-composite-indicators-and-scoreboards.pdf

Fazio, G. Maioli, S. & Rujimora, N. (2024)). The twin innovation transitions of European regions, *Regional Studies*, DOI: 10.1080/00343404.2024.2309176

Filippi, E., Bannò, M. &Trento, S. (2023). "Automation technologies and their impact on employment: A review, synthesis and future research agenda", *Technological Forecasting and Social Change*, 191. https://doi.org/10.1016/j.techfore.2023.122448.

Fragkiadakis, K., Vrontisi, Z., Fragkiadakis, D., Hurley, J., Staffa, E., & Paroussos, L. (2023). Fit for 55 climate package: Impact on EU employment by 2030, Eurofund, Publications Office of the European Union. DOI:10.2806/522425

Helsper, E. (2021). *The Digital Disconnect: The Social Causes and Consequences of Digital Inequalities*, SAGE Publications Ltd. ISBN: 9781526492975.

Jämsä-Jounela, S.L. (2007). "Future trends in process automation", *Annual Reviews in Control*, 31(2):211-220. https://doi.org/10.1016/j.arcontrol.2007.08.003.

Karabarbounis, L. & Neyman, B. (2014). The Global Decline of the Labor Share. *Quarterly Journal of Economics*, 129(1), 61-103

Kostarakos, I. and Marques Santos, A., (2024). Territorial Economic Data viewer: An Introduction to the Industrial module, European Commission, Joint Research Centre, Publications Office of the European Union, Seville, JRC140343.

Maucorps, A, Römisch, R.,Schwab, T. & Vujanović, N.(2023) : The future of EU cohesion: Effects of the twin transition on disparities across European regions, wiiw Research Report, No. 467, The Vienna Institute for International Economic Studies (wiiw)

McDowall, W, Reinauer, T., Fragkos, P., Miedzinski, M. & Cronin, J (2023). "Mapping regional vulnerability in Europe's energy transition: development and application of an indicator to assess declining employment in four carbon-intensive industries", *Climatic Change*, 176(7), https://doi.org/10.1007/s10584-022-03478-w

McKinsey Global Institute. (2017). *Jobs lost, jobs gained: Workforce transitions in a time of automation*. McKinsey & Company.

Muluneh, M.G. (2021). “Impact of climate change on biodiversity and food security: a global perspective - a review article”, *Agriculture & Food Security* 10. https://doi.org/10.1186/s40066-021-00318-5

OECD (2008). “Handbook on Constructing Composite Indicators: Methodology and User Guide”

Restrepo, P. (2024). Automation: Theory, Evidence and Outlook. *Annual Reviews of Economics*, 16, 1-25

Rodríguez-Pose, A. & Bartalucci, F. (2024). “The green transition and its potential territorial discontents”, *Cambridge Journal of Regions, Economy and Society*.

Rosés, J. R., & Wolf, N. (2021) Regional inequality in the long-run: Europe, 1900-2015, Oxford Review of Economic Policy, 37: 17–48

Santos, A. M.; Barbero, J.; Salotti, S. and Conte, A. (2023a). "Job creation and destruction in the digital age: Assessing heterogeneous effects across European Union countries", Economic Modelling, 126. https://doi.org/10.1016/j.econmod.2023.106405

Santos, A.; Barbero, J.; Salotti, S.; Diukanova, O. and Pontikakis, P. (2023b). “On the road to regional ‘Competitive Environmental Sustainability’: the role of the European structural funds”, Industry and Innovation, 30:7, 801-823, DOI: 10.1080/13662716.2023.2236048

Schnabel, I. (2022). A new age of energy inflation: climateflation, fossilflation and greenflation. Speech at a panel on “Monetary Policy and Climate Change” at The ECB and its Watchers XXII Conference

Schwab, K. (2017). *The fourth industrial revolution*. Crown Currency.

Susskind, D. (2020). *A world without work: Technology, automation and how we should respond*. Penguin UK.

Vandeplas, A., Vanyolos, I., Vigani, M., & Vogel, L. (2022). *The possible implications of the green transition for the EU labour market*. Publications Office of the European Union.

Vona, F. (2023). Managing the distributional effects of climate policies: A narrow path to a just transition. *Ecological Economics*, *205*, 107689.

Vrontisi, Z., Charalampidis, I., Fragkiadakis, K., Florou, A., Römisch, R and Jestl, S. (2022). Report on current socioeconomic, demographic, energy, and socio-political challenges in carbon intensive regions. Carbon Intensive Regions in Transition - Unravelling the Challenges of Structural Change project

Weber, J. G. (2020). How should we think about environmental policy and jobs? An analogy with trade policy and an illustration from US coal mining. Review of Environmental Economics and Policy, 14(1):44-66. https://doi.org/10.1093/reep/rez016

List of figures

List of tables

Annexes

Annex 1. Data sources

This Appendix contains further details on the definitions and the sources of the variables employed in the empirical analysis presented in the main text for which additional manipulations were necessary.

- 1. Change in CO2 emissions: calculated as the long difference (from 1990 to 2019) of C02 emissions per capita from fossil fuels, obtained from ARDECO [EDGARP].
- 2. Cooling and heating degree days: obtained from the Energy statistics - cooling and heating degree days database of Eurostat (series nrg_chddr2_a)
- 3. Electricity prices, households and non-households: obtained from the Energy statistics, natural gas and electricity prices database of Eurostat (series: nrg_pc_204 and nrg_pc_205)
- 4. Emissions per capita: ARDECO [EDGARP].
- 5. Employment in brown sectors: the brown are defined as the most-polluting sectors, i.e. the sectors with the highest level of emissions. These are identified on the basis of regionalized country-level emission intensity data by NACE sector of economic activity. The corresponding codes of the sectors that comprise the list of brown sectors is: A, B, C19, C20, C23, C24, D, E, H49, H50 and H51.
- 6. Green and digital cohesion expenditures: in order to arrive at this split of expenditures, the cohesion projects are being categorized as being either green or digital on the basis of text-mining analysis. The source of the cohesion projects is Kohesio data platform, available here: https://kohesio.ec.europa.eu/en/
- 7. Green patents: the source of the patents dataset is KNOWMAK. We categorize as green the patents falling under the following thematic areas: climate action, affordable and clean energy and responsible consumption and production.
- 8. Human capital index: constructed using regional levels of educational attainment obtained by Eurostat, which are then converted to years of schooling. In turn, these are converted into the measure of human capital using a standard Mincerian human capital function. Further details can be found in Beugelsdijk et al. (2018)
- 9. Private sector investment: private investment (and, in general, investment by institutional sector) is not available at the regional NUTS2 level. To this end, we approximate it by making use of the Gross Fixed Capital Formation by industry series available in ARDECO. In particular, our private investment measure comprises the investment expenditures of the following sectors: A, B-E, F, G-J, K-N.

Annex 2. Further statistical analysis

Prior to the calculation of the indicator we implemented some statistical analysis based on the guidelines of the 10 steps guide of the JRC-COIN. Firstly, we examined our data in order to assess whether outliers are present. We report that the results for skewness and kurtosis indicate that we can proceed without the need to treat for outliers e.g. via winsorizing our data.

Further, in order to assess the statistical and conceptual coherence of the index we computed the correlation coefficients between the composite indicators and their respective components. This will allow us to assess whether some of the components are either under-represented or they significantly load on the resulting indicator. We report that the correlations observed are within the prescribed range and conform to the theory.

Getting in touch with the EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

— by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

— at the following standard number: +32 22999696,

— via the following form: european-union.europa.eu/contact-eu/write-us_en.

Finding information about the EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

EU open data

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

Science for policy

The Joint Research Centre (JRC) provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society

EU Science Hub
Joint-research-centre.ec.europa.eu