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Are EU regions ready to tackle climate change?

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Are EU regions ready to tackle climate change?

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Executive Summary

In recent years, a growing body of research literature has emphasised the imperative of directing innovation efforts towards addressing pressing societal challenges (Weber & Rohracher, 2012; Mazzucato, 2018; Schot & Steinmueller, 2018). Notably, climate change stands as a paramount concern for policymakers, necessitating a concerted focus on finding innovative solutions. Gearing innovation policy toward creating public good (Uyarra et al., 2019) hints at orienting several stakeholders and resources in the same direction (Weber & Rohracher, 2012).

Our analysis sheds light on the complexity of the geography of readiness in tackling climate change. This analysis contributes to the territorialisation of the so-called 'mission-oriented approach', aiming to direct innovation policies towards addressing societal challenges. While this debate tends to focus on the national and international scales, the readiness to tackle climate change was investigated at the regional level across the main EU member states.

The paper provides quantitative evidence on the geography of regional readiness to tackle climate change using data from France, Germany, Italy, Poland, and Spain. Following Cappellano et al. (2022), we estimate a composite indicator that reports the situation of regions in these countries between 2009 and 2020 regarding the directionality of their Science and Technological Innovation and policy priorities to fight climate change.

Using regression analysis, we assess the relationship between such directionality and the degree of risk of disasters (coastal floods, river floods, and landslides) they face in the short, medium, and long-term as a result of climate change effects. Results shows that readiness to tackle climate change is driven by the combination of factors: regions at higher risks, more R&D intensity and more skilled human capital are more 'ready' to engage with this societal challenge. This outcome affirms, firstly, the existence of interregional dissimilarities in the adoption of a mission-oriented approach to combat climate change, and secondly, the collective mobilization of EU territories in response to the climate crisis.

However, this mobilization by more developed and high-risk regions raises concerns about two other categories of regions. A major threat exists for regions with high risk and low technological and human capital resources. These less developed regions show low degrees of readiness to tackle climate change that is likely to have major implications on their territories.

Conversely, advanced regions facing lower climate risks appear less inclined to prioritize confronting the climate crisis, a choice with ramifications extending far beyond their regional confines. Policymakers should be aware of these differences in the readiness to tackle climate change to make sure everyone is on board for today's most pressing challenge.

In sum, our study advances our comprehension of the geographic dimensions underlying the capacity to address climate change. It underscores the necessity for nuanced strategies that encompass diverse regional

realities, ensuring a holistic and effective approach to combat this global challenge. As we embark on a journey to confront the complexities of climate change, these insights are pivotal for steering policy, fostering collaboration, and safeguarding our shared future.

Are EU regions ready to tackle climate change?

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Disclaimer: (*) The views expressed are purely those of the author and may not in any circumstances be regarded as stating an official position of the European Commission.

Abstract

This paper provides quantitative evidence on the geography of regional readiness to tackle climate change using data from France, Germany, Italy, Poland, and Spain. Following Cappellano et al. (2022), we estimate a composite indicator that reports the situation of regions in these countries between 2009 and 2020 regarding the directionality of their Science and Technological Innovation and policy priorities to fight climate change. Using regression analysis, we assess the relationship between such directionality and the degree of risk of disasters (coastal floods, river floods, and landslides) they face in the short, medium, and long-term as a result of climate change effects. Results shows a positive relationship between estimated risk and climate change preparedness. However, a more in-depth analysis demonstrates the complexity of such geographical "problem-solution convergence". Indeed, more developed regions are the ones that appear more ready to tackle climate change effects compared with transition and less developed regions. Policymakers should be aware of these differences in the readiness to tackle climate change to make sure everyone is on board for today's most pressing challenge.

Keywords: Climate Change; Innovation; Public Policy; Regional Economics; Europe.

JEL code: Q54; Q55; Q58; R11; O52.

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1. Introduction

In recent years, a growing body of research literature has emphasised the imperative of directing innovation efforts towards addressing pressing societal challenges (Weber & Rohracher, 2012; Mazzucato, 2018; Schot & Steinmueller, 2018). Notably, climate change stands as a paramount concern for policymakers, necessitating a concerted focus on finding innovative solutions. Gearing innovation policy toward creating public good (Uyarra et al., 2019) hints at orienting several stakeholders and resources in the same direction (Weber & Rohracher, 2012). We want to explore if European regions are ready to orient their research and innovation (R&I) endeavours to address societal challenges, with climate change as a central priority, to foster more significant societal impact and sustainable development.

This trend is commonly summarised by the so-called 'mission-oriented approach'. In short, this approach envisages to turn R&I actions and investments towards a clear, measurable, and time-bound objective with a broad societal value (Mazzucato, 2018). The 'mission-oriented approach' is a terminology that follows up on similar, sometimes overlapping, notions such as 'research for societal challenges' and 'responsible research and innovation'. In fact, those approaches hinge on the fundamental assumption "big science should be applied to big problems" (Ergas, 1987). Therefore R&I policies should aim to tackle societal challenges. This approach was mainstreamed in the policy landscape leading to the uptake of the EU's Missions, while several other national programmes in Europe and worldwide have followed a similar approach orienting innovation policies to address societal challenges (European Commission 2018; Larrue, 2021; Robinson et al, 2021). However, these approaches have been mainly framed at the national or supranational scale (e.g., the EU), with limited attention to the implications and the resources available at a sub-national scale.

In this paper, we concentrate on the regional scale, as a new stream of literature has started to pop up concerning the "micro-missions" (Henderson, Morgan & Delbridge, 2023) and the "small-scale activities" (Bours et al., 2021). Tackling climate change requires actions at multiple levels, not only the national/supranational ones. For this reason, we narrow down our analysis to the regional scale as (I) not all territories are equally exposed to the same threats induced by climate changes (Flanagan, Uyarra, and Wanzenböck 2021), (II) administrative capacities vary across regions with further implications on their regional strategy effectiveness (Capello & Kroll, 2016; Rodríguez-Pose, di Cataldo, & Rainoldi, 2014), (III) the composition of industry sectors with diverse environmental footprint varies on a geographical base (OECD, 2021); (IV) orchestrating actors within regional innovation ecosystems requires examining established knowledge bases, the industrial specialisation of regions, and incumbent firms (Bugge et al. 2021). For these reasons, climate actions should be tailored to the different intra-national situations.

This study adopts a regional approach to investigate the strategic intelligence of local stakeholders that are called to collectively organise their activities to achieve sustainable targets (Kirchherr, et al., 2023). Through a quantitative approach, the researchers inspect the geography of regional readiness to tackle this societal challenge by adopting the RE-SCORE index, which combines regional data about the directionality from science, technology, and innovation (STI) data with the policy viewpoints (cf. Cappellano et al., 2022). The analysis of intra-national heterogeneities in the readiness to tackle climate change focuses on the five largest EU member states (France, Germany, Italy, Poland, and Spain). This sample is selected as major interregional differences are expected. Furthermore, these countries are also the main beneficiaries of the EU's Cohesion Policy and Horizon funds framework.[3]

Our study is conceived under threefold steps. First, we process empirical data to depict a geography of regional readiness to tackle climate change through the RE-SCORE. Second, we assess the relationship between the readiness to tackle climate change and regional characteristics. The final step concerns the geographical "problem-solution convergence": are the regions - most at risk to be affected by climate change - also the ones most ready to address this societal challenge? To assess this relationship empirically, a pooled OLS regression is estimated to explain how place-specific conditions, including the degree of disaster risk regions, are faced due to climate change, are related to the regional readiness proxied through the RE-SCORE index. Data are extracted from several sources, namely Eurostat, European Commission's Risk Data Hub, KNOWMAK, Horizon dashboard and Bachtrögler et al. (2021).

Findings expand the understanding of the geography of challenge-oriented innovation *vis-à-vis* the geography of innovation (cf. Balland et al., 2019; Balland & Rigby, 2017). This analysis contributes to the existing literature deepening the geographical (mis-)match between exposure to environmental threats led by climate change and regional readiness – both in terms of R&I and policy directionality. This research assesses the relationship between administrative quality and R&I capacity toward the regional readiness to tackle climate change. This mismatch draws policy lessons to implement a place-based regional innovation policy geared to tackle climate change.

2. Literature Review

Innovation policy is aimed to create, exploit, and share knowledge - throughout the multiple phases of the innovation process – to bridge scientific breakthroughs into marketable products/process/service (Edler & Fagerberg, 2017). Since the 1990s, the innovation policy has gained a wider prominence across policymakers for its beneficial economic effects that innovation engenders for the region or country where it is originated (Fagerberg, 2016). While innovation policy was originally narrowly focused on securing prosperity and economic growth, there is now more consensus on orienting innovation toward societal challenges (Schot & Steinmueller, 2018; Weber & Rorhacher, 2012).

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[3] Under the programming period 2014-2020, they accounted for about 60% of the EU budget for Research and Innovation funded by Cohesion Policy and they were able to attract a similar proportion of the Horizon framework budget (Marques Santos et al., 2023).

In this new ethos, the mission-oriented approach envisages to direct investments and R&I actions towards a clear, measurable, and time-bound objective with a broad societal value (Mazzucato, 2018). As Mazzucato & Perez (2015) resumed, it is not only a matter of "rate" (how much economic value the innovation policy generates) but also a question of "route" (where the innovation policy is leading). The idea of "orienting" innovation toward challenges with significant societal value consolidated into a "normative" turn for policymakers (Uyarra, et al., 2019). Yet, "addressing Grand Challenges is a challenge in its own right, for policy as well as for science, technology, and innovation actors" (Kuhlmann & Rip, 2018, p.488). As Kuhlmann & Rip (2018) synthesise, tackling societal challenges might require a substantially new understanding of innovation policy with a sharp shift from a centralised agency to a more distributed form of governance including heterogeneous stakeholders (see also Schot & Steinmuller, 2018; Tödtling et al., 2021; Howoldt & Borrás, 2022).

As Haddad et al (2022) summarised, there are plenty of approaches that encapsulate the new ethos of policy to tackle societal challenges, such as the "grand challenge programs" (Hayter and Link, 2020), "transformative innovation policy" (Steward, 2012), "mission-oriented policies" (Foray, 2018; Mazzucato, 2018), and the "challenge-oriented regional innovation systems" (CoRISs) (Isaksen et al., 2022). Other scholars hybridised the term "missions" with the large literature stream of sustainable transitions into "sustainability missions" (Kirchherr, et al., 2023). Nevertheless, most of the approaches may fall into the so-called "transformative innovation policy" that aims to target societal challenges with innovation policy by arranging new practices and changes in the administrative and organisational capacities of public institutions (Haddad et al., 2022).

The mission-oriented approach envisages a centrality of (national) governments to set bold and inspirational targets (Mazzucato, 2018), informing the uptake of EU Missions, under the Horizon Europe program. However, this approach received critiques as it proved hard to "combine the engagement of citizens in the mission's definitions and the design of an inclusive orientation process that does not lead to an inflation, broadening or dilution of ambitions" (Larrue, 2021. P. 90). The need to coordinate actors aligning them to the same direction to avoid the so-called "directionality failure" (Weber & Rorhacher, 2012), adds a territorial layer to the complex interplay between directionality-actors-place within the innovation policy design and management. While main challenge-oriented innovation policy concepts address the first two elements, a small batch of research populated the literature on how regions should be included in the societal challenges-oriented innovation policy narrative (Hassink et al., 2022).

From a theoretical perspective, there is limited knowledge concerning the governance of missions as required horizontal alignment between sectoral ministries that are directly related to the societal challenges (Larrue, 2021) as well as vertical coordination with sub-national governments (Wanzenböck & Frenken, 2020; Cappellano & Kurowska-Pysz, 2020; Parks, 2022). An example that received major attention is the EU's Horizon Missions, with priorities set at the national and European levels. In contrast, several scholars suggested that the framing practice should follow a place-based approach to reflect on local values and priorities (cf. Flanagan, Uyarra, and Wanzenböck 2021). Involving subnational tiers should yield a more solid legitimacy (Kuhlmann & Rip, 2018). On the contrary, imposing a narrowly technological perspective to the definition of Societal Challenge, the challenge-oriented innovation policy might be neglecting place-specific beliefs, values, and social attitudes (Wanzenböck et al., 2020). In fact, different solutions – not necessarily technological - for the same challenge can be applied in different regional contexts (Flanagan, Uyarra, and Wanzenböck 2021). In this respect, the mid-term evaluation of EU missions (Reid et al., 2023) suggests that there is a need for participatory approaches to the definition of missions as well as the framing and selection of mission areas is reported to require a deeper understanding of the social factors that drive or hinder change. The report highlights that R&I efforts per se cannot be sufficient to secure missions' targets, instead the implementation of innovation is critical to achieve significant targets (Reid et al., 2023). From a policy perspective, scholars criticised the narrow technological understanding of innovative solutions to be adopted (Janssen et al., 2021; Larrue, 2021; Wanzenböck & Frenken, 2020). Instead, they claimed that adopting a regional perspective on challenge-oriented R&I policy is critical to consider the existing ongoing policy dynamism (Janssen et al., 2021), adapting solutions to the specific contexts through micro-missions that may have further benefits in terms of local knowledge (Henderson, Morgan & Delbridge, 2023). A regional approach to challenge-oriented R&I policy might anchor local projects to national or supranational Missions that are proved to yield considerable results at local level on the global societal challenges (Bours et al., 2021), as well as the established knowledge bases, the industrial specialisation of regions, and incumbent firms (Bugge et al., 2021), the specific exposure to societal challenge-led threats (Flanagan, Uyarra, and Wanzenböck 2021). This study extends the understanding of the regional mission-oriented approach as it takes into account the place-specific quality institutions to facilitate policy learning (Hassink et al., 2022), the misalignment between science and technological innovation and policy directionality (Cappellano et al., 2022).

This research aims to advance the literature discussed, adopting a regional perspective to the mission-oriented approach innovation policy geared to tackle climate change, as defined in Horizon 2020. Building on the evidence that a highly innovative regional profile constitutes a necessary but not sufficient condition to be ready to tackle societal challenges (Cappellano et al., 2022), we inspect regional potential across a large sample of EU regions considering both policy and technological capabilities.

3. Towards the regional readiness: because both technology and policy matters

The mission-oriented approach and other innovation policy concepts (see Smart Specialisation Strategy) have been extensively criticised for having a predominant focus on technological innovation (Trippl et al., 2021; Larrue, 2021). Some new studies underline how the alignment of local knowledge base with the policy directionality is a critical element to tackle societal challenge (Bugge et al., 2021; Cappellano et al., 2022). A massive quantity of studies has populated the literature inspecting the role of technological innovation in mitigating climate change which has been confirmed to be critical (Irandoust, 2016). Seamlessly, Mensah et al. (2019) confirm that technological innovation supports green growth in 28 OECD economies. Their analysis disentangled the effects upon the technological sector engendering evidence with mixed results per each geographical context (at the continental level).

At the regional level, evolutionary economic geographers have investigated whether regions can shape their business portfolio under a new development pathway oriented to mitigate emissions. Several studies assessed quantitatively that related regional knowledge bases are conducive for regions to succeed in diversifying their portfolio into green technologies (Montresor & Quatraro, 2020; Santoalha & Boschma, 2021), although recognising a minor yet critical role of regional political support (Santoalha & Boschma, 2021). In fact, there is evidence that policy – and most notably policy tools – generates positive environmental effects. For instance, Rodriguez et al. (2019) simulated a tax reform in Portugal to assess whether it would positively affect economic and environmental performances. Although, the cleaner industry sectors benefited the most at the expense of carbon-intensive businesses (ibidem).

Recent quantitative studies surfaced in the literature substantiating the effect of policy to influence firms' environmental innovation or performance. Notably, Kyaw (2022) empirically demonstrated that policy uncertainty generates a persistent effect on firms' environmental innovation, hampering the promotion of environmental sustainability and the fight against climate change. Consistently, Lucena-Giraldo et al. (2002) assess quantitatively that policy affects firms' environmental performance by improving eco-innovating efforts. However, we need studies combining the two (complimentary) fields, measuring both inputs from the Science and Technological Innovation and Policy directionality to tackle climate change.

On the other hand, our paper investigates where policymakers have been targeting societal challenges upon the reported risk of their territories being hit by climate change-led effects. There have yet to be studies published available in this field. However, it is very much needed how European regions have been preparing to offset the effects of climate change and mitigate their emissions as a source of climate change. This study contributes to the literature on challenge-oriented R&I policy by investigating the directionality of both scientific and technological regional ecosystems as well as policy interventions. The first study about RE-SCORE proved a weak alignment between STI and policy orientation towards societal challenges in Italian regions (see Cappellano et al., 2022). This paper expands the geographical scope of analysis to understand the alignment between scientific and innovation ecosystems and policy institutions in regions from 5 EU member states. Such extensive research design is complementary to case study analysis conducted to assess the alignment of missions (see Parks, 2022). Here, the analysis highlights the strategic intelligence to couple the two regional ecosystems with the knowledge about the exposure to natural risks generated by climate change.

In so doing, the analysis shed light on the capacities of local stakeholders, which have been receiving attention in the challenge-oriented innovation discourses (see Borras et al., 2023). The mission-oriented approaches are contested to require institutional capacities to tailor policy mix to combine supply-push and demand-led policy instruments (Larrue, 2021). Although a deep assessment of the institutional capacities of regional governments is not in the scope of this paper, this analysis contributes to assessing whether and how the EU regions have been able to sum a critical mass of investments from both the EU's Cohesion Policy and Horizon fundings in attempt to close the gap between the territorial and research policy instruments.

4. How to measure the readiness to tackle climate change?

While there are plenty of studies inspecting regional technological proficiency to specialise in green technologies (e.g., Santoalha & Boschma, 2021; Montresor & Quatraro, 2020; Wang & Zhu, 2020), there is a weak understanding of how regions as both administrative and scientific institutions can align their stakeholders and capacities to tackle climate change (Weber & Rohracher, 2012). This paper innovates the literature by shedding light on the geography of regions ready to tackle this Societal Challenge. The analysis hinges on the RE-SCORE index, which combines regional data about the directionality from Science & Technological Innovation (STI) and policy viewpoints (Cappellano et al., 2022). Such a research strategy is conceived to offer more "general" trends examining regions from the five largest populated EU Member states: Germany, Poland, Italy, France, and Spain. Our study is conceived under threefold steps: 1) we process empirical data to depict a geography of regional readiness to tackle climate change through the RE-SCORE; 2) we will assess the relationship between the readiness to tackle climate change and regional characteristics. The final step (3) will concern the geographical "problem-solution convergence" which means investigating whether the most polluting regions are the ones most ready to target climate change through an underway effort to reduce their environmental footprint, according to their economic portfolio.

To measure readiness to tackle climate change, a similar methodological approach developed by Cappellano et al. (2022) for the Italian regions is applied in this analysis. The authors created a composite indicator with five dimensions that allow for capturing the directionality of STI and policy priorities. This indicator, called 'Regional Societal Challenges-Oriented Readiness' (RE-SCORE) index takes into account:

- Capacity to generate knowledge in area i;
- Integration in research networks in area i;
- Attitude towards applying for patents in area i;
- R&I policy directionality in area i;
- Capability in attracting EU's research funding in area i.

Where area i corresponds to four EU's Grand Societal Challenges: bioeconomy, climate change, health and inclusive society.

For the present paper, the authors estimated the RE-SCORE for the societal challenge of climate change only. The selected countries are France, Germany, Poland and Spain, in addition to Italy as in Cappellano et al. (2022). Considering the scope of the study, the indicator is branded as 'Readiness to tackle Climate Change' (RCC). Following Cappellano et al. (2022), the RCC combines data from KNOWMAK, Bachtrögler et al. (2021) and the Horizon dashboard, as described in Table 1.

Table 1. Dimensions, description and data behind the RCC indicator

Dimensions	Description	Period	Data source
Capacity to generate knowledge	Publications in the area of climate change	2009-2016	RISIS-KNOWMAK
Integration in research networks	EU-FP coordinated project in the area of climate change	2009-2016	RISIS-KNOWMAK
Attitude towards applying for patents	Patents applications in the area of climate change	2009-2016	RISIS-KNOWMAK
R&I policy directionality	Concentration of R&I Cohesion Policy funds associated with the thematic area "climate action, environment, resource efficiency and raw materials" (2014-2020)	2014-2020	Bachtrögler et al. (2021)
Capability in attracting research funding	Concentration of Horizon 2020 in the thematic area “climate action, environment, resource efficiency and raw materials” (2014-2020)	2014-2020	Horizon dashboard

Source: Own elaboration based on Cappellano et al. (2022).

Following Cappellano et al. (2022), raw data are retrieved from the different data sources, thereafter, aggregated at the same regional unit (NUTS-2) and normalised by population for the selected period from 2009 to 2016. Afterwards, outlier values are identified and removed from the data used in determining the maximum and minimum scores in the normalisation process. The normalisation leads to the third step, in which maximum and minimum scores are calculated for each dimension for the whole period for all the French, German, Italian, Polish, and Spanish NUTS-2 regions. Finally, the min-max normalisation procedure is used to re-scale scores, limiting distortion.

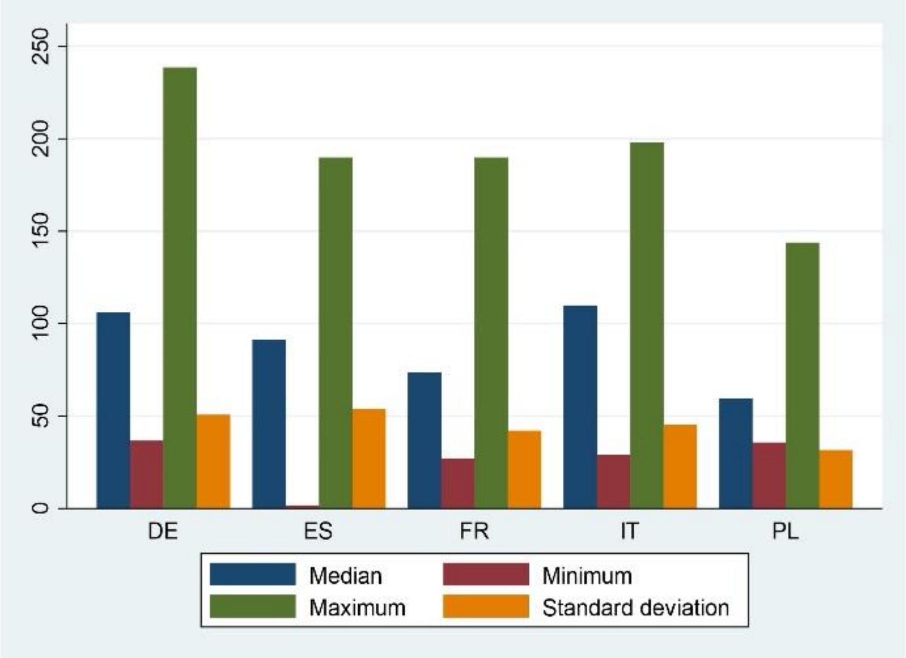
The RE-SCORE offers a unique yet simple indicator that captures both STI and policy directionality at the regional level. Such a quantitative approach allows comparing a more comprehensive range of regions enabling researchers to draw trends regarding multiple variables. At the same time, it is noted that the RE-

SCORE mainly captures technological innovation, as there is no significant EU-wide database for other forms of innovation (e.g. social) at regional level. The capacity to attract Horizon 2020 funding may reflect the administrative capacity of regional agencies to handle successful proposals. While this is in line with RE-SCORE's intention to take stock of regional readiness by combining administrative, business, and technological capacities to address SC, it could increase the disparities between regions with different capacity endowments. However, Cappellano et al. (2022) show that not necessarily competitive Italian regions - as usually defined by the innovation benchmark - can make a significant contribution to tackling SCs.

5. Regional Readiness to tackle Climate Change (RCC)

Figure 1 presents the median, minimum, maximum, and standard deviation values of the regional data observed for each country for the RCC indicator. Poland (PL), France (FR), and Spain (ES) report the lowest median value, while Germany (DE) and Italy (IT) report the highest. The minimum value recorded in a region is in Spain, whereas the highest is in Germany. The box plots (Figure 2) also show a higher indicator variability among Spanish, Italian, and German regions compared to Polish and French regions. This heterogeneity is confirmed by the geographical distribution of the RCC indicator, as reported in Figure 3.

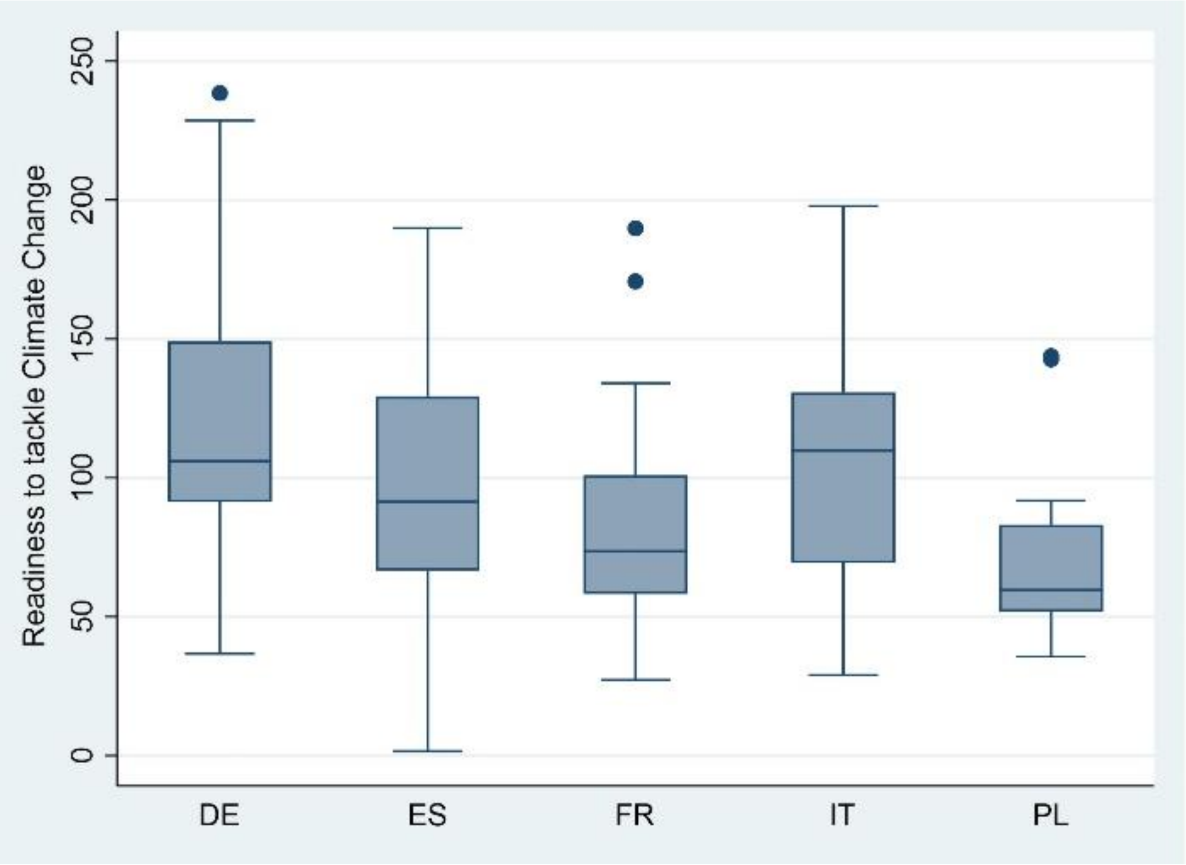
Figure 1. RCC by country: median, mean, minimum and maximum



Source: Authors'own estimation.

Note: RCC refers to the 'Readiness to tackle Climate Change' index.

Figure 2. Box plots RCC by country

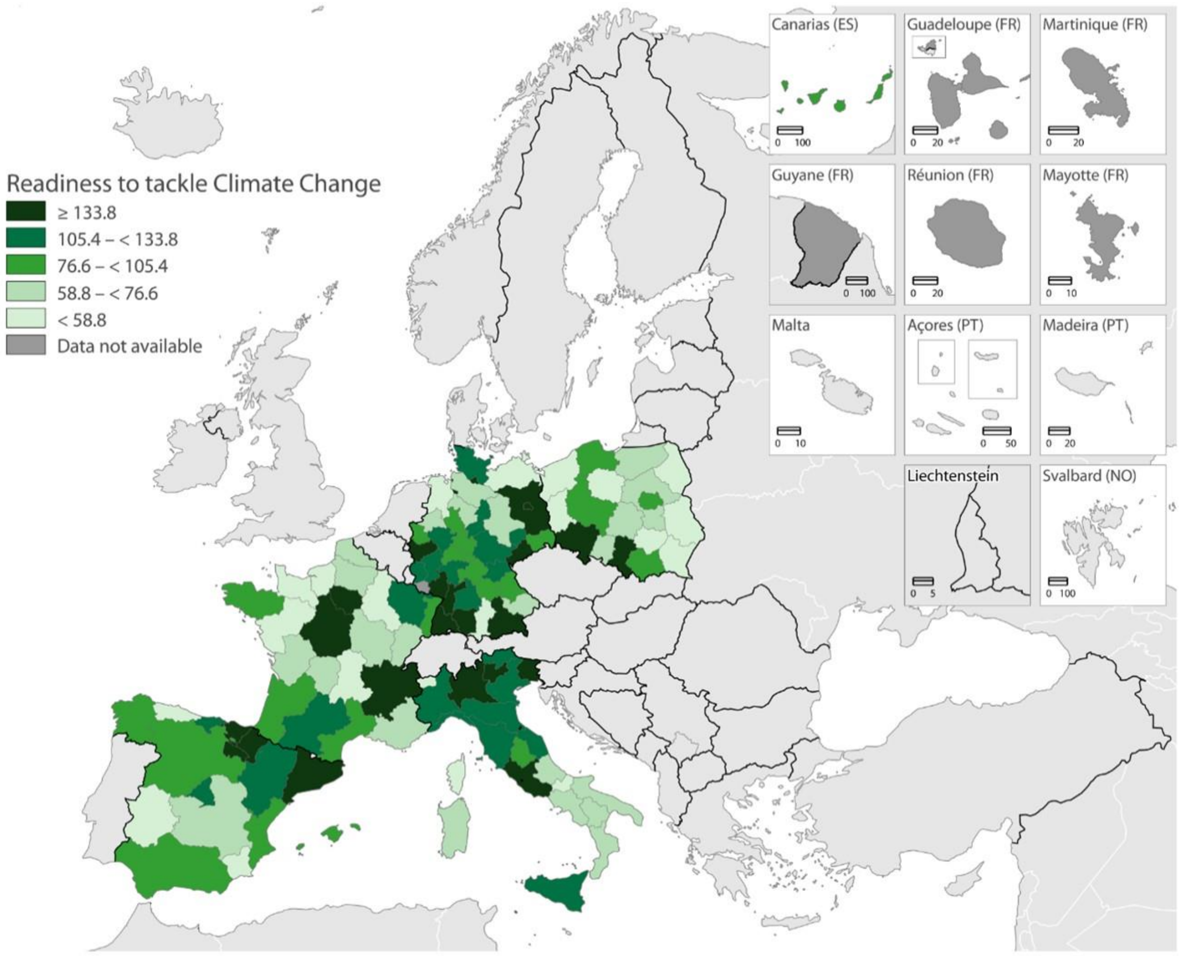


Source: Authors'own estimation.

Note: RCC refers to the 'Readiness to tackle Climate Change' index.

Continued on next page

Figure 3. Geographical distribution of the RCC indicator



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Cartography: Eurostat – IMAGE, 06/2023

Source: Authors'own estimation.

Note: RCC refers to the 'Readiness to tackle Climate Change' index.

The RCC performances across the Member States assessed reveal a new geography which is far less straightforward than expected. Italian regions do not respect the typical North-South divide. On the contrary, only Lazio (ITI4), Lombardy (ITC4), the Province of Trento (ITH2) and Friuli Venezia-Giulia (ITH4) outperform the rest of the country. According to the Regional Innovation Scoreboard (European Commission et al., 2023), the Friuli Venezia Giulia and the Province of Trento are regions listed as Strong Innovators. Instead, Lazio and Lombardy are reported as Moderate Innovators. Yet several other regions classified in the same category did not reach a similar RCC performance.

Similarly, German regions do not respect the historical trend between the Western and Eastern parts of the country. In fact, the Brandenburg (DE40) performance is reported higher compared to other German regions. Such a performance can be explained for a few reasons: a) the region hosts the city of Potsdam where the most important German research center on climate change is located – the Potsdam Institute on Climate Change (PIK), also being one of the most prominent CC R&I centers across the EU; b) the region encapsulates the city state of Berlin with abundance of research, innovation and business development generating economic spill-overs into Brandenburg hinging on the physical proximity and a larger supply of land as well as favourable tax regime; and c) is one of the Bundeslaender hit hardest by climate change causing already serious droughts and occasional flash floods, hence is also a welcome target for all the researchers from Berlin for studies and experimentation.

While Freiburg (DE13) matches the high innovation leader position with remarkable RCC performance, surprisingly overcomes many other German regions. Against all odds, Germany shows a rather new North-South divide: coastal regions underperform, with the notable exception of Schleswig-Holstein on the border with Denmark. Instead moving higher values are recorded in regions towards the Alps.

In France and Spain, a more traditional geography emerges. Paris (i.e., Ile-de-France, FR10) and Rhone-Alpes (FRK2) show higher RCC values and are the most economically developed regions. Along the same line, the capital region is surrounded by a 'ring' of low-performing regions. Similarly, Spanish regions follow the usual pattern, with Madrid and the North-Eastern regions performing higher than the rest of the country. A surprising result comes from Andalusia (ES61), with quite high performances.

In Poland, the usual East-West divide is only partially emerging in the southern part. Furthermore, two regions that are least ranked for their innovation profile appear to have the best RCC performances as their strategies are based on environmental protection.

6. Looking for the drivers

To estimate the empirical relationship between the region's readiness to tackle climate change (RCC) and the degree of disaster risk they are faced ($RISK$), we use the model expressed in equation (1):

$$RCC_i = f(RISK_i, X_i) \tag{1}$$

Where X_i refers to a set of control variables that, according to scientific literature about the drivers of innovation directionality (see Nyiwul, 2021), are able to influence our dependent variable. Therefore, X_i includes Research and Development activities (RD), technological advancement (TA), agglomeration economies (AG) and institutional quality (IQ). We also control for the degree of air pollution in the region, including the Greenhouse Gases emissions (GHG) in the model. Indeed, we expect that most polluting regions may be influenced to investment more in climate-neutral innovations (Wang et al., 2020; Pan et al., 2021; Irfan et al., 2022; Wen et al., 2023). For more details about the variables included in the model, see Table 2. Descriptive statistics of the variables are reported in Table A1 in Appendix.

Table 2. Explanatory variables description and data source

Variable	Description	Source
RISK	Level of estimated risk of three disasters (coastal floods, river floods and landslides), where risk is defined as the potential loss or damage to society (i.e. population) after an expected exposure of 2, 10 or 25 years.. The combined risk level corresponds to the average of three types of disaster risk levels using an indicator approach.	European Commission's Risk Data Hub
GHG	Stock of total greenhouse gases (GHG) in 2009 refers to the cumulative values of emissions from 1990 to 2009. Emissions include CO2 (fossil only), CH4, N2O and F-gases; and they are expressed in kilo tonnes CO2 equivalent	Own estimation based on the Emissions Database for Global Atmospheric Research (EDGAR) – Crippa et al. (2022)
RD	R&D intensity proxied by the share of R&D stock over total capital stock in 2009; Stocks are estimated using the Perpetual Inventory Method (PIM) and depreciation rates of 20% for R&D stock and 8% for capital stock following Montresor and Vezzani (2015)	Own estimation based on Eurostat: gross fixed capital formation [nama_10r_2gfcf] and gross expenditures on R&D [rd_e_gerdtot]
TA	Within-country technological advancement in 2009 is proxied by the inverse distance to the frontier, where the frontier refers to the maximum observed value of Gross Value Added (GVA) per capita within a country	Own estimation based on Eurostat: GVA [nama_10r_3gva] and population [demo_r_d2jan]
AG	Agglomeration economies are proxied by within-country regional concentration of the share of employment with tertiary education (over total employment, 15-64 years) in 2009; it is estimated by the ratio between the share of employment tertiary education in a region over the share of employment tertiary education in the country.	Own estimation based on Eurostat: employment [lfst_r_lfe2emprtn]
IQ	Institutional quality is proxied by the European Quality of Government Index in 2010	Charron et al. (2014)

As our dependent variable measures the average readiness of region i to tackle climate change in the period 2009-2020 (as described in section 3.1), all control variables (except IQ) refer to the situation of the region at the beginning of the period under analysis (2009), to avoid reverse causality bias. For the IQ, we use the year 2010, as this is the first year with available data.

Taking the logarithms[4] of (1), we obtain equation (2), which also includes a country dummy (δ_i) and an error term (ε_i). Taking into account the nature of the dependent variable, equation (2) is estimated using a Pooled OLS.

$$lnRCC_i = \beta_0 + \beta_1 lnRISK_i + \beta_2 lnGHG_i + \beta_3 lnRD_i + \beta_4 lnTA_i + \beta_5 lnAG_i + \beta_6 lnIQ + \delta_i + \varepsilon_i \qquad (2)$$

The main assumption behind our model (2) lies in the fact that regions are pushed to re-direct innovation and institutional efforts to fight climate change due to socio-economic losses or damages the region may be faced in the future as the effect of climate change, however, regional features may also affect the directionality. For instance, agglomeration economies may be conducive to complex knowledge (Balland & Rigby, 2017). The quality of government may shape regional innovative performance in the EU Regions (Rodriguez-Pose & Di Cataldo, 2015). Innovation input such as the R&D stock are also pre-conditions for developing and concentrating innovation activities in few key regions (for instance, Florida, et al., 2017).

7. Results

7.1. Descriptive Statistics

Figure 4 and Figure 5 report the median of the RCC indicator and the median of the estimated disaster risk by region category based on the classification of the regions under the 2021-2027 Cohesion policy. Figure 4 shows that more developed regions have higher RCC values; whereas, according to Figure 5, the level of risk is higher in transition regions, followed by more developed regions. Less developed regions are the ones with a lower level of disaster risk. When estimating the ratio between the RCC and level of risk (Figure 6), we observe that more developed regions are the ones that appear more ready to tackle climate change effects compared with transition and less developed regions.

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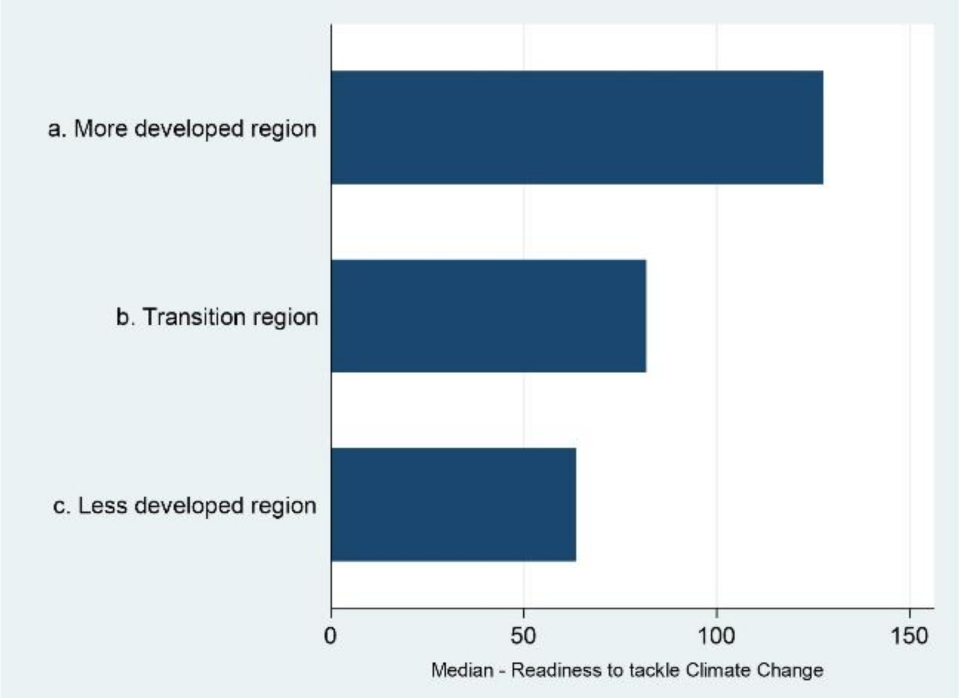
[4] As IQ has negative values, we added a constant value to the data before applying the log transform. Such constant is equal to one minus the minimum of IQ: lnIQ = ln(IQ + 1 – min(IQ)). For other variables with a minimum equal to zero (see Table A1 in Appendix), we also added a constant, before log transform, equal to one.

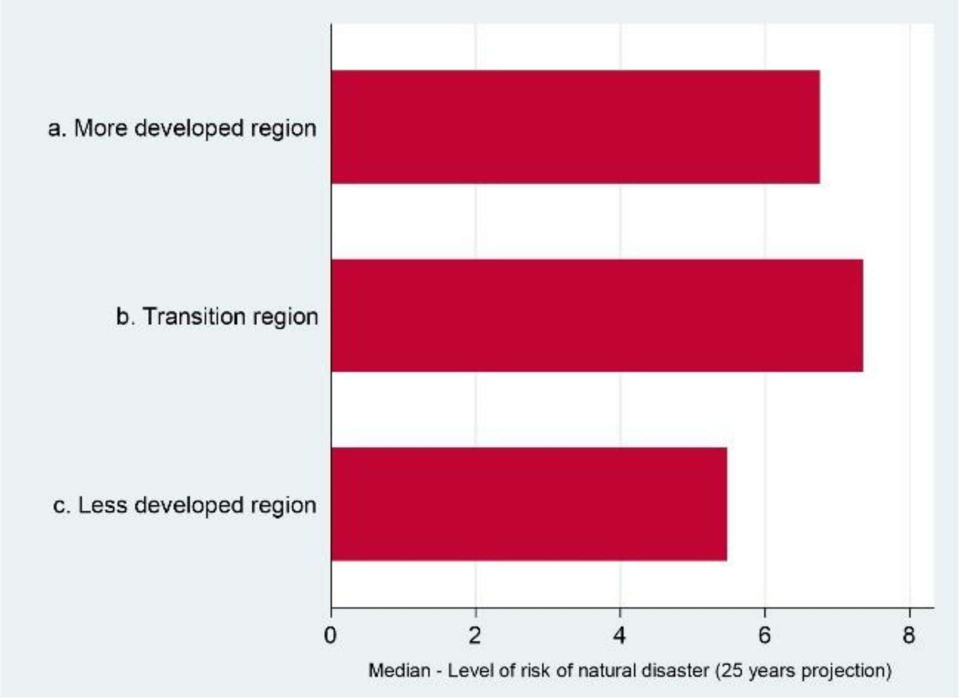
Figure 4. Median RCC by region categories (Cohesion criteria 2021-2027)



Source: Authors'own estimation.

Note: RCC refers to the 'Readiness to tackle Climate Change' index.

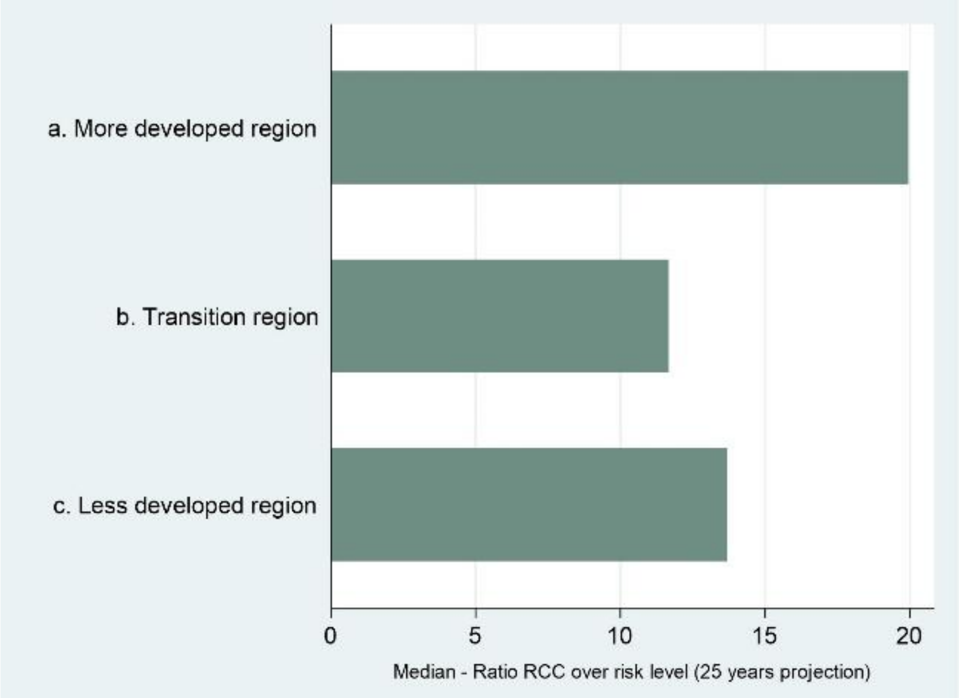
Figure 5. Median of the risk (estimated over 25 years) by region categories (Cohesion criteria 2021-2027)



Source: Own estimation based on European Commission's [Risk Data Hub.]

Note: Level of risk estimations of combined disasters coastal floods, river floods and landslides.

Figure 6. Median RCC over risk by region categories (Cohesion criteria 2021-2027)



Source: Own estimation based on data from Figure 4 and Figure 5.

Note: Level of risk estimations of combined disasters coastal floods, river floods and landslides.

Table 3. Level of risk and readiness to tackle climate change (RCC), sample median and median by country

Country	Estimated Risk (25 years)	Readiness to tackle climate change (RCC)
DE	6.82	105.96
ES	6.06	97.82
FR	7.45	73.57
IT	6.01	109.85
PL	5.74	59.63
Sample	6.61	92.36

Table 4. Number of regions with a level of risk above (below) the median and a readiness to tackle climate change above (below) the EU sample or within country median, by region categories (Cohesion criteria 2021-2027).

Category of regions	**Risk >= Median & RCC >= Median**		**Risk < Median**		**Risk >= Median & RCC < Median**		**TOTAL**
	Nr	% Total	Nr	% Total	Nr	% Total	Nr
Threshold within country median							
More developed	19	40%	22	46%	7	15%	48
Transition	12	29%	17	41%	12	29%	41
Less developed	5	21%	17	71%	2	8%	24
Threshold EU sample median							
More developed	21	44%	22	46%	5	10%	48
Transition	11	27%	14	34%	16	39%	41
Less developed	1	4%	21	88%	2	8%	24

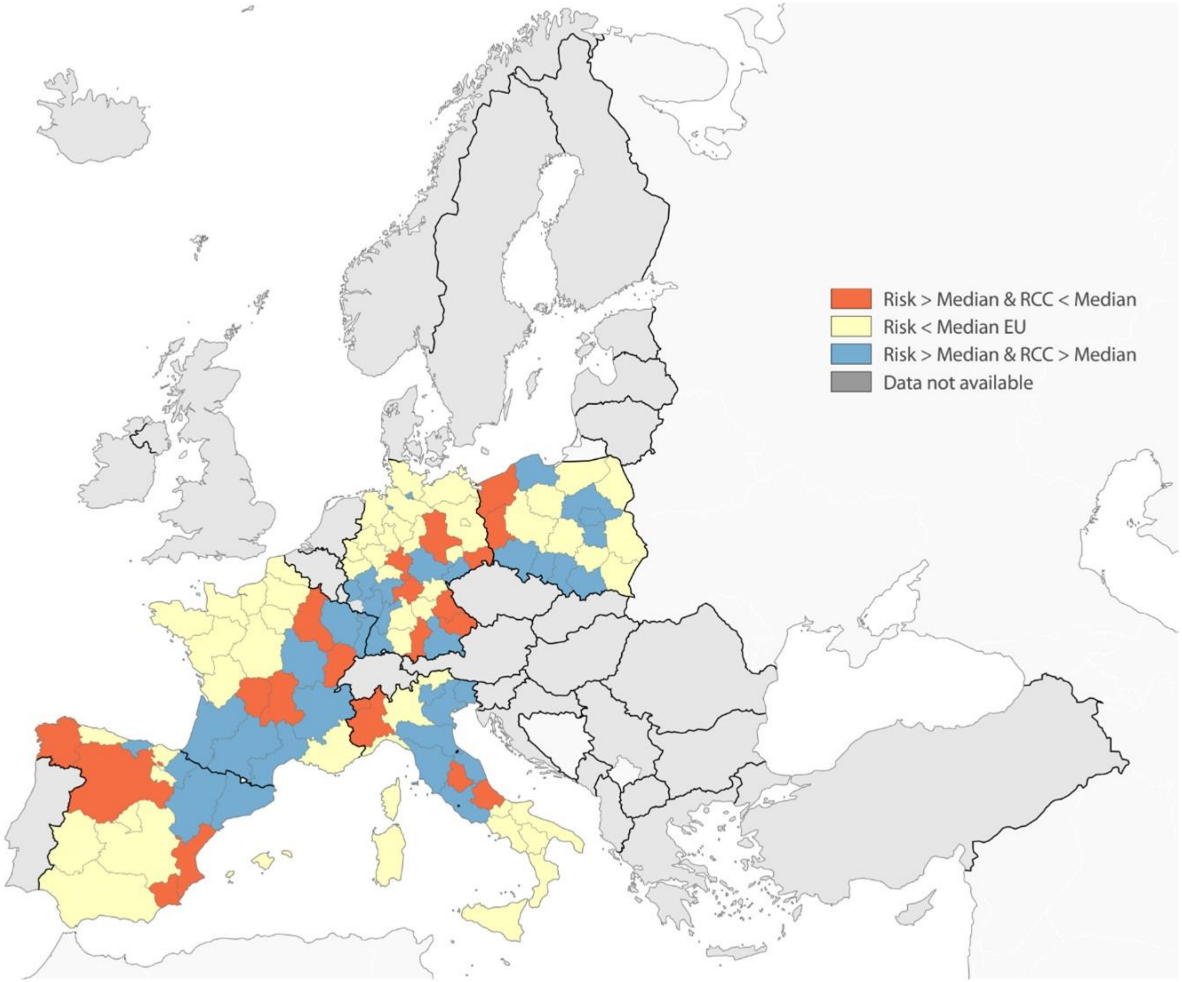
Source: Authors' own estimation.

Note: Estimated Risk over 25 years. Category of regions refers to Cohesion Criteria for the programming period 2021-2027.

Figures 7 and 8 below report the level of risk and readiness to tackle climate change (RCC) by sample and country median. The comparison of the two median values facilitates accounting for national effects. The case of Italy is a good example: regions with higher values within the country (in blue in figure 7) show lower values vis-à-vis the sample median (in red in Figure 8). This result shows the poor readiness of Italy as a country. Similar comparisons can be made for the other countries in the sample.

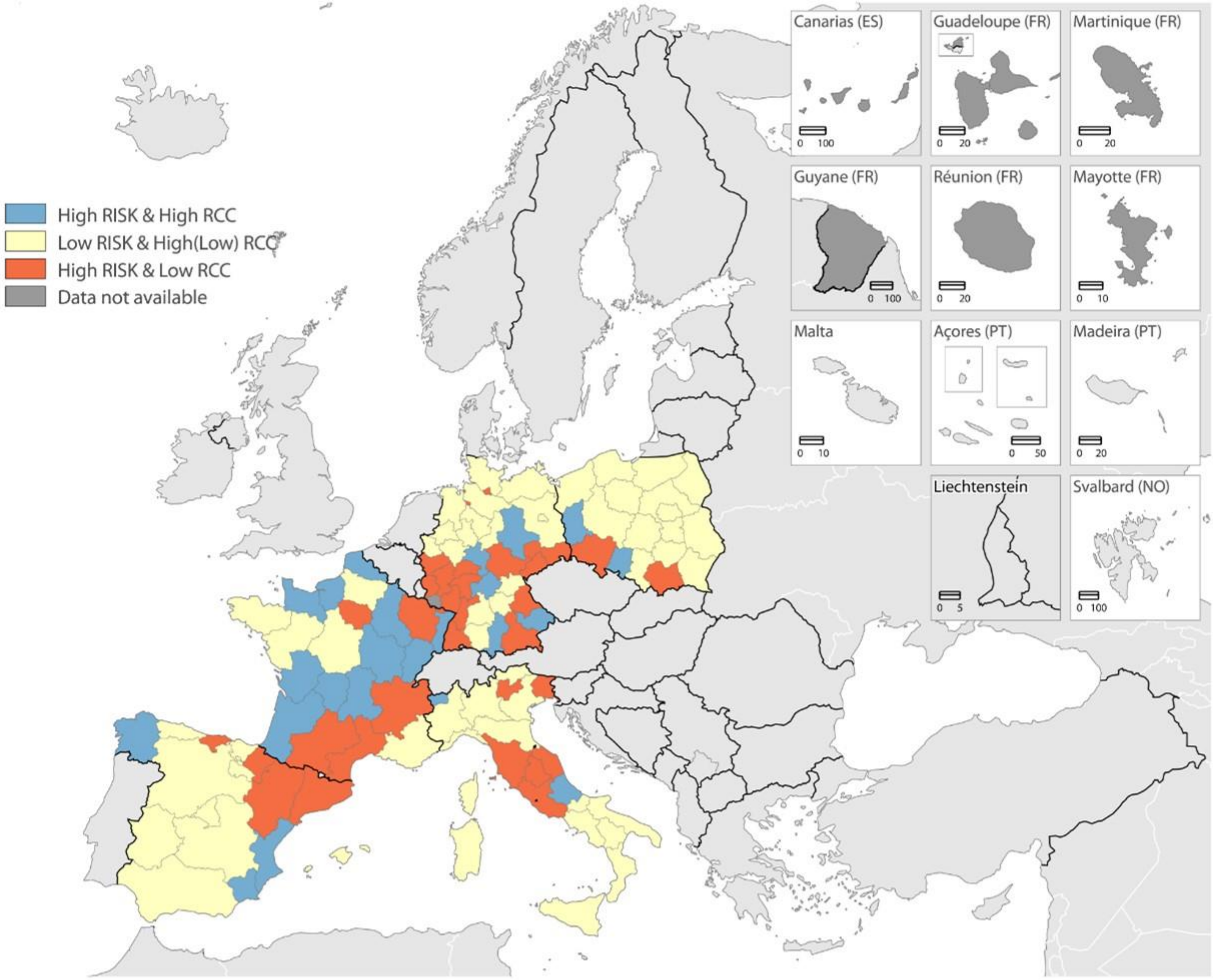
The key message is that the intra-national perspective always needs a European benchmark as the national effect is still highly relevant, though with some country-specificities. Nonetheless, the regional perspective proposed by our article helps highlight the interregional differences within each member state. Therefore, European decision-makers need to keep both perspectives together.

Figure 7. Classification of regions by the level of risk to natural disasters and their readiness to tackle climate change face to within country median



Administrative boundaries: © EuroGeographics © UN–FAO © Turkstat
Cartography: Eurostat – IMAGE, 07/2023

Figure 8. Classification of regions by the level of risk to natural disasters and their readiness to tackle climate change face to EU sample median



Administrative boundaries: © EuroGeographics © UN–FAO © Turkstat
Cartography: Eurostat – IMAGE, 06/2023

7.2. Results of regression estimation

The results of the log-log pooled OLS estimation are displayed in

Table 5. The dependent variable is the readiness to tackle Climate Change (RCC). The primary explanatory variable is the level of risk estimations of combined disasters (coastal floods, river floods and landslides), where risk is defined as the potential loss or damage on society after an expected exposure of 2 years (column 1), 10 years (column 2) or 25 years (column 3) from 2022 onwards. The validation tests reported at the bottom of Table 4 demonstrate that the model has a significant overall fit and it is not suffering from omitted variable bias. The results are not biased by collinearity issues (Table A2 – Appendix A) and robustness checks demonstrate the stability of the results after adding or removing explanatory variables (Table B1 – Appendix B).

Table 5. Results Pooled OLS regression, dependent variable RCC (log)

Variables	(1)	(2)	(3)
Risk – 2 years (log)	0.237**	-	-
	(0.0983)	-	-
Risk – 10 years (log)	-	0.234**	-
	-	(0.0979)	-
Risk – 25 years (log)	-	-	0.234**
	-	-	(0.0980)
Stock GHG (log)	0.0423	0.0422	0.0419
	(0.0588)	(0.0589)	(0.0590)
R&D intensity (log)	0.330***	0.329***	0.329***
	(0.0737)	(0.0737)	(0.0737)
Technological advancement (log)	1.145*	1.146*	1.147*
	(0.608)	(0.607)	(0.607)
Agglomeration (log)	1.965*	1.965*	1.960*
	(1.001)	(1.000)	(0.997)
Institutional quality (log)	-0.375	-0.377	-0.380
	(0.305)	(0.305)	(0.305)
Country dummy	Yes	Yes	Yes
Constant	3.193***	3.199***	3.206***
	(0.828)	(0.829)	(0.829)
Observations	113	113	113
R-squared	0.465	0.464	0.464
Joint significance test (p-value)	0.0000	0.0000	0.0000
Omitted variables test (p-value)	0.3015	0.3144	0.3230
Joint significance country dummy (p-value)	0.0695	0.0703	0.0702
Z-test: Beta Risk 2 years vs 10 years (p-value)	0.6012		
Z-test: Beta Risk 2 years vs 25 years (p-value)	0.6012		

Note: Robust standard errors in parentheses. Significance level: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

The coefficients of the variable risk estimation in 2, 10 or 25 years show a positive and significant relationship with climate change preparedness. These results suggest that higher levels of risk are associated with higher levels of preparedness of the regions to deal with climate change. In line with Nyiwul (2021) who found a positive empirical relationship between water-related adaptation technologies and climate-induced vulnerability in the water sector in Africa. The value of the elasticity in the short term (0.237) does not vary too much compared to the elasticity in the medium and long term (0.234). The z-test also shows that the different coefficients are not statistically different.

As expected, innovation intensity and technological advancement are positive and significantly correlated with the readiness to tackle climate change. These results imply that more innovative and technologically advanced regions report higher values for our composite indicator measuring the directionality of STI and policy priorities in tackling Climate Change issues. They also confirm previous findings that R&D intensity Nyiwul (2021) influence positively climate adaptation technologies.

Agglomeration economies, measured by the concentration of highly skilled workers in a region, is positively associated with higher values of readiness to tackle climate change. This confirms that potential advantages, as knowledge absorption, spillovers and transfer, of industries being located close to others in a specific area tend to drive the directionality of STI. It also suggests that skilled human capital has a higher likelihood to support this knowledge production, in line with Nyiwul (2021) and Wen et al. (2023).

The stock of greenhouse gas emissions is not statistically significant, contrary to the findings of Wang et al (2020) and Pan et al. (2021) for China and Wen et al. (2023) for a worldwide country-level analysis. In the framework of the present study, our results eventually reveal that other macroeconomic factors are more important in explaining the readiness to tackle climate change in the European regions under analysis. The institutional quality is also a non-significant variable, as Nyiwul (2021) also found for the water sector in Africa, probably for the same previous reason.

8. Conclusion

Our analysis sheds light on the complexity of the geography of readiness in tackling climate change. The impacts of climate change and the different orientations towards addressing this societal challenge varies across space. This analysis contributes to the territorialisation of the so-called ‘mission-oriented approach’, aiming to direct innovation policies towards addressing societal challenges. While this debate tends to focus on the national and international scales, the readiness to tackle climate change was investigated at the regional level across the main EU member states.

Tackling climate change requires the integration of the administrative and scientific capabilities with the policy directionality. The analysis of the readiness to tackle climate change has shown that new geographies emerge that are different from the ‘traditional’ interregional disparities within EU countries. For instance, the well-known Italy's North-South divide or the Germany's East-West differences are much more articulated. In line with the previous exercise (Cappellano et al., 2022), solid economic profile and R&D performance makes a necessary but not sufficient precondition for regional readiness to tackle Societal Challenges.

In fact, the readiness to tackle climate change is driven by the combination of risks, R&D intensity and human capital concentration: regions at higher risks, more R&D intensity and human capital are more 'ready' to engage with this societal challenge. This outcome affirms, firstly, the existence of interregional dissimilarities in the adoption of a mission-oriented approach to combat climate change, and secondly, the collective mobilization of EU territories in response to the climate crisis.

However, this mobilization by more developed and high-risk regions raises concerns about two other categories of regions. A major threat exists for regions with high risk and low technological and human capital resources. These less developed regions show low degrees of readiness to tackle climate change that is likely to have major implications on their territories. Conversely, advanced regions facing lower climate risks appear less inclined to prioritize confronting the climate crisis, a choice with ramifications extending far beyond their regional confines. Policymakers should be aware of these differences in the readiness to tackle climate change to make sure everyone is on board for today's most pressing challenge.

Our methodological decision to focus on the largest EU member states has brought to light substantial intranational disparities. Nevertheless, future inquiries should encompass the entire spectrum of EU regions and potentially extend the analysis beyond the EU, though we are aware of existing data constraints. The climate crisis engenders disparate consequences across scales, mandating that decision-makers navigate this intricacy while inclusively engaging all stakeholders. Furthermore, this approach holds promise for adaptation to other pressing societal challenges such as poverty, ageing and biodiversity loss.

In sum, our study advances our comprehension of the geographic dimensions underlying the capacity to address climate change. It underscores the necessity for nuanced strategies that encompass diverse regional realities, ensuring a holistic and effective approach to combat this global challenge. As we embark on a journey to confront the complexities of climate change, these insights are pivotal for steering policy, fostering collaboration, and safeguarding our shared future.

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Appendix

Appendix A. Descriptive Statistics and Collinearity Diagnostics

Table A1. Mean, Standard deviation, Minimum and Maximum

Variable	Obs	Mean	Std. dev.	Min	Max
RCC	113	101.0	48.1	17.4	238.5
Risk - 2 years	113	6.405	1.877	0	10
Risk - 10 years	113	6.403	1.882	0	10
Risk - 25 years	113	6.421	1.882	0	10
Stock GHG	113	515,410	382,766	27,163	1,922,885
R&D intensity	113	2.90	2.25	0.22	11.97
Technological advancement	113	0.584	0.169	0.312	1
Agglomeration	113	0.996	0.044	0.825	1.11
Institutional quality	113	0.18	0.81	-1.95	1.28
Germany (DE)	113	0.33	0.47	0	1
Italy (IT)	113	0.19	0.39	0	1
France (FR)	113	0.19	0.40	0	1
Spain (ES)	113	0.14	0.35	0	1
Poland (PL)	113	0.15	0.36	0	1

Table A2. Collinearity Diagnostics and correlation matrix

#	Variables	VIF	Correlation matrix					
			#1	#2	#3	#4	#5	#6
#1	Risk - 2 years (log)	1.25	1	-	-	-	-	-
#2	Stock GHG (log)	1.24	-0.048	1	-	-	-	-
#3	R&D intensity (log)	1.96	0.311	0.312	1	-	-	-
#4	Technological advancement (log)	1.49	0.201	-0.052	0.320	1	-	-
#5	Agglomeration (log)	1.64	0.079	-0.063	0.118	0.419	1	-
#6	Institutional quality (log)	2.08	0.382	-0.052	0.509	0.168	0.441	1
	Mean VIF	1.61						

Appendix B. Robustness checks

Table B1. Robustness checks: results Pooled OLS regression, dependent variable RCC (log)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Risk - 2 years (log)	0.352***	0.314***	-	-	-	-	-	-	-
	(0.0994)	(0.112)	-	-	-	-	-	-	-
Risk - 10 years (log)	-	-	0.352***	0.314***	-	-	-	-	-
	-	-	(0.0993)	(0.112)	-	-	-	-	-
Risk - 25 years (log)	-	-	-	-	0.358***	0.318***	-	-	-
	-	-	-	-	(0.0993)	(0.112)	-	-	-
Stock GHG (log)	-	-	-	-	-	-	0.130**	-	-
	-	-	-	-	-	-	(0.0644)	-	-
R&D intensity (log)	-	-	-	-	-	-	-	0.433***	-
	-	-	-	-	-	-	-	(0.0668)	-
Technological advancement (log)	-	-	-	-	-	-	-	-	2.526***
	-	-	-	-	-	-	-	-	(0.559)
Agglomeration (log)	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
Institutional quality (log)	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
Country dummy	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes
Constant	3.808***	3.661***	3.808***	3.660***	3.796***	3.653***	2.511***	4.237***	3.293***
	(0.188)	(0.183)	(0.188)	(0.183)	(0.188)	(0.184)	(0.827)	(0.0974)	(0.195)
Observations	113	113	113	113	113	113	113	113	113
R-squared	0.054	0.165	0.054	0.166	0.056	0.167	0.174	0.376	0.310
Joint significance test (p-value)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Omitted variables test (p-value)	0.9532	0.9430	0.9542	0.9317	0.9637	0.9259	0.1318	0.2121	0.2971
Joint significance country dummy (p-value)	-	0.0022	-	0.0021	-	0.0021	0.0003	0.0026	0.0055

Continue on the next page…

Note: Robust standard errors in parentheses. Significance level: *** p<0.01, ** p<0.05, * p<0.1.

Table B1. Robustness checks: results Pooled OLS regression, dependent variable RCC (log) – (Continuation)

Variables	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Risk - 2 years (log)	-	-	0.341***	0.244**	0.192*	0.207**	0.237**	-	-
	-	-	(0.111)	(0.104)	(0.0970)	(0.0965)	(0.0983)	-	-
Risk - 10 years (log)	-	-	-	-	-	-	-	0.234**	-
	-	-	-	-	-	-	-	(0.0979)	-
Risk - 25 years (log)	-	-	-	-	-	-	-	-	0.234**
	-	-	-	-	-	-	-	-	(0.0980)
Stock GHG (log)	-	-	0.139**	0.0346	0.0585	0.0587	0.0423	0.0422	0.0419
	-	-	(0.0644)	(0.0613)	(0.0615)	(0.0615)	(0.0588)	(0.0589)	(0.0590)
R&D intensity (log)	-	-	-	0.403***	0.297***	0.320***	0.330***	0.329***	0.329***
	-	-	-	(0.0732)	(0.0752)	(0.0730)	(0.0737)	(0.0737)	(0.0737)
Technological advancement (log)	-	-	-	-	1.514***	1.103*	1.145*	1.146*	1.147*
	-	-	-	-	(0.553)	(0.592)	(0.608)	(0.607)	(0.607)
Agglomeration (log)	2.301**	-	-	-	-	1.247	1.965*	1.965*	1.960*
	(0.993)	-	-	-	-	(0.861)	(1.001)	(1.000)	(0.997)
Institutional quality (log)	-	0.280	-	-	-	-	-0.375	-0.377	-0.380
	-	(0.291)	-	-	-	-	(0.305)	(0.305)	(0.305)
Country dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	4.231***	3.979***	1.818**	3.378***	2.609***	2.753***	3.193***	3.199***	3.206***
	(0.101)	(0.237)	(0.833)	(0.813)	(0.812)	(0.828)	(0.828)	(0.829)	(0.829)
Observations	113	113	113	113	113	113	113	113	113
R-squared	0.173	0.139	0.215	0.398	0.447	0.456	0.465	0.464	0.464
Joint significance test (p-value)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Omitted variables test (p-value)	0.0629	0.5214	0.6937	0.2594	0.4406	0.3588	0.3015	0.3144	0.3230
Joint significance country dummy (p-value)	0.0026	0.0043	0.0006	0.0011	0.0283	0.0092	0.0695	0.0703	0.0702

Note: Robust standard errors in parentheses. Significance level: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

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