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Regional R&I ventures to tackle climate change: A new geography of challenge-oriented innovation landscape

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A B S T R A C T

This paper analyses how EU regions have aligned their innovation and policy endeavours to tackle exposure to the effects of Climate Change at regional level. Scholars hailed the need to orienting efforts and resources to tackle societal challenges. However, we have little empirical evidence on the alignment of R&I ecosystems and policy endeavours towards tackling Climate Change. Using regression analysis, we assess the relationship between such directionality and the exposure to risk of disasters (i.e., coastal floods, river floods, and landslides) that each region faces in the short, medium, and long term due to Climate Change. Results show a positive relationship between risk projection and climate change preparedness. However, a more in-depth analysis demonstrates the complexity of such geographical "problem-solution convergence": investigating whether the EU regions most at risk of being affected by climate change are also the ones most ready to target climate change through an aligned combination of R&I and policy efforts. Findings show that more developed regions appear more ready to tackle climate change effects compared to transition and less developed regions. These findings suggest that more support is needed for less developed regions facing major Climate Change-related risks.

1. Introduction

The quest for tackling Climate Change has gained prominence due to the multiple threats caused worlwide, including in Europe. Policymakers are confronted with this urgent need at all government levels, while researchers have emphasised the imperative of directing innovation efforts towards addressing pressing societal challenges (Mazzucato, 2018; Schot and Steinmueller, 2018; Weber and Rohracher, 2012). 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 hints at orchestrating several stakeholders and resources in the same direction (Uyarra et al., 2019; Weber and Rohracher, 2012).

Several policy models have been proposed in the scientific literature, such as the mission-oriented approach (Mazzucato, 2018), transformative innovation policy, sustainable innovation or challenge-oriented innovation policy (see Haddad et al., 2022). A common feature of all models is the need to target societal challenges as an end goal. The 'fil rouge' of these approaches is the aim of turning research and innovation (R&I) policies and investments towards a clear, measurable, and time-bounded objective with a broad societal value (cf., Mazzucato, 2018). This mission-oriented approach is grounded on the assumption that "big science should be applied to big problems" (Ergas, 1987). Therefore, it is expected that R&I policies should aim to tackle societal challenges (Mazzucato, 2018).

In Europe, this approach was mainstreamed in the policy landscape (European Commission, 2018), leading to the uptake of the EU's Horizon Missions (see Cappellano et al., 2024 for a deeper discussion). Several other national R&I programmes in Europe and worldwide have adopted a similar approach, orienting innovation policies to address societal challenges (see Larrue, 2021; Robinson et al., 2021; Rohracher, Coenen and Kordas, 2023; Rohracher and Ornetzeder, 2024). However, these approaches have been mainly framed at the national or supranational scale with limited attention to the implications and available

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resources at a sub-national scale.

Within this scientific literature, the few available studies at the regional level have been limited to qualitative analyses (see Hassink et al., 2022; Cappellano, Uyarra and Flanagan, 2024). This paper aims to provide the first quantitative study on how EU regions have aligned their innovation and policy endeavours to tackle exposure to climate change effects at regional level. We want to explore whether European regions are ready to focus their R&I efforts on societal challenges, with climate change as the key priority.

This paper advocates for a regional-level focus in climate action research. The increasing emphasis on 'micro-missions' (Henderson, Morgan and Delbridge, 2023; Bours et al., 2021) and the spatially varied impacts of climate change (Fastenrath et al., 2023; Flanagan et al., 2023) highlight the region as a crucial governance level. Regions are well-placed to implement challenge-oriented innovation policies due to their proximity to local needs and capacities (Bugge et al., 2022; Henderson, Morgan, and Delbridge, 2023; Flanagan et al., 2023). Moreover, sub-national governance enables tailored responses to diverse regional economic structures with varying concentrations of 'green' and 'brown' industries and administrative capacities (OECD, 2021; Capello and Kroll, 2016; Rodríguez-Pose et al., 2014).

While acknowledging the spatial mismatch between pollution sources and climate impacts, this study aims to investigate whether regions most exposed to climate change-related disasters are also engaged in challenge-oriented R&I policy. To the best of our knowledge, the academic literature has not yet addressed this aspect.

The regional approach adopted in our analysis aims to investigate the collective strategic intelligence of regional stakeholders called to organise their activities to achieve sustainable targets (Kirchherr et al., 2023). 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, developed by Cappellano et al. (2022). This composite indicator combines regional data about the policy directionality in tackling climate change. Specifically, our analysis contains the five largest EU member states (France, Germany, Italy, Poland, and Spain) to highlight inter-regional differences within the selected countries. Furthermore, these countries are also the primary beneficiaries of the EU's Cohesion Policy and Horizon funds.[2] Second, we integrate the climate-change-related risks for EU regions. Data are extracted from several sources: the European Commission's Risk Data Hub (2024), Eurostat, and Horizon dashboard, as well as, KNOWMAK and Bachtrögler et al. (2021) datasets.

The third, and final step concerns the geographical "problem-solution convergence": are the EU regions most at risk of being affected by climate change also the ones most ready to address this societal challenge? For the empirical assessment of this relationship, a pooled OLS regression is estimated to explain how place-specific conditions, including the degree of climate change-caused disasters, are related to the regional readiness to tackle such a societal challenge, as proxied through the RE-SCORE index.

Our findings expand the understanding of the geography of challenge-oriented innovation *vis-à-vis* the geography of innovation mainly focused on economic competitiveness (cf. Balland et al., 2019; Balland and Rigby, 2017). The study innovates the literature on EU R&I funding distribution across EU regions (cf., Dotti and Spithoven, 2018; Santos and Conte, 2024) by processing a regional data index focused on climate change. This analysis contributes to the existing literature, deepening our understanding of the geographical (mis-)match between exposure to climate change-caused environmental threats and the regional readiness to tackle such a challenge. This (mis)match draws policy lessons to implement a place-based regional innovation policy geared to tackle climate change, highlighting discrepancies between economic development, R&I policy orientation and exposure to climate change-related risks.

The remainder of the paper is structured as follows. Section 2 reviews the literature, starting from the mission-oriented approach to STI policy. Section 3 presents the importance of investigating regional readiness to tackle climate change. Section 4 presents the materials and methods used to calculate the index of regional readiness to tackle climate change, as in Section 5. The empirical analysis is further developed in Section 6, looking for the drivers of regional readiness, with results in Section 7. Section 8 concludes.

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/processes/services (Edler and Fagerberg, 2017). Since the 1990s, the innovation policy has gained a wider prominence among policymakers for its beneficial economic effects (Fagerberg, 2017). While innovation policy was initially narrowly focused on securing prosperity and economic growth, there is now more consensus on orienting innovation toward societal challenges (Schot and Steinmueller, 2018; Weber and Rohracher, 2012).

As Haddad et al. (2022) summarised, several approaches now encapsulate this new ethos, 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 extensive literature on sustainable development, forging the expression "sustainability missions" (Kirchherr et al., 2023). Nevertheless, most approaches fall into the so-called "transformative innovation policy" that aims to target societal challenges with innovation policy by arranging new practices and changes in public institutions' administrative and organisational capacities (Haddad et al., 2022). The idea of 'orienting' innovation toward challenges with significant societal value represents a normative turn for policymakers (Uyarra et al., 2019).

From a theoretical perspective, we want to discuss the question of scale for challenge-oriented policies. As Kuhlmann and Rip (2018) synthesise, tackling societal challenges requires 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 Howoldt and Borrás, 2022; Lupova-Henry and Dotti, 2019; Schot and Steinmueller, 2018; Tödtling et al., 2022). The challenge is to avoid the so-called "directionality failure" (Weber and Rohracher, 2012) when actors fail to coordinate and align their priorities. This challenge adds a territorial layer to the complex interplay among directionality, actors and places for the design and implementation of innovation policy (see Wanzenböck et al., 2020).

Instead, the mission-oriented approach envisages a centrality of (national) governments to orient innovation policies towards a clear, measurable, and time-bounded objective with a broad societal value (Mazzucato, 2018). However, limited knowledge exists concerning the 'horizontal' coordination mechanism, that is, across sectoral ministries (Larrue, 2021) and the vertical ones, i.e. between national and subnational (Wanzenböck and Frenken, 2020; Cappellano and Kurowska-Pysz, 2020; Parks, 2022). As Cappellano, Molica and Makkonen (2024) discussed, the EU Missions could benefit from a thorough territorial perspective considering local policy attempts to tackle societal challenges, local knowledge and exposure to societal challenges, and the existing subnational policy dynamism (Bours et al., 2021; Bugge et al., 2022; Janssen et al., 2021; Flanagan et al., 2023). In this perspective, the micro-missions aim to adopt a place-based approach to enable context-specific solutions and incorporate local values and priorities (Henderson et al., 2023; Flanagan et al., 2023) because involving subnational tiers should yield more legitimacy (Kuhlmann and Rip,

[2] In the programming period 2014-2020, the selected Member States accounted for about 60% of the budget for each EU policy (Marques Santos et al., 2023).

2018).

The literature on challenge-oriented policies—including Missions—has predominantly addressed national programs (see Larrue, 2021; Rohracher, Coenen and Kordas, 2023; Rohracher and Ornetzeder, 2024). While studies inspecting challenge-oriented policies at the regional level have been limited to qualitative case studies (see Hassink et al., 2022; Cappellano, Uyarra and Flanagan, 2024)

Our study extends the understanding of the regional mission-oriented approach by considering the place-specific engagement with societal challenges, the possible (mis) alignment between science and technological innovation and policy directionality (Cappellano et al., 2022; Hassink et al., 2022).

This research aims to advance the literature discussed by adopting a regional perspective on the mission-oriented approach to innovation policy geared to tackling climate change. To the best of our knowledge, this is the first quantitative study on how EU regions have aligned their innovation and policy endeavours to tackle climate change locally.

First, we want to explore whether EU regions are ready to focus their innovation policy on climate change. Second, we want to estimate whether the EU regions most exposed to climate change-led disasters have been more active in orienting their STI and innovation policies towards climate change. Our objective is to fill this gap in the literature to integrate the regional dimension in the mission-oriented policy debate.

3. The alignment of science, technology and policy toward climate change

A major stream in the scientific literature explored the role of technological innovation in mitigating climate change, which has been confirmed to be critical (Irandoust, 2016). For instance, Mensah et al. (2019) seemingly 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 geographical area, i.e., continental context.

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 (Santoalha and Boschma, 2021, Montresor and Quatraro, 2020;), although recognising a minor yet critical role of regional political support (Santoalha and Boschma, 2021). The literature also identified the evidence of the positive impacts of policy tools on the environment. For instance, Rodriguez et al. (2019) simulated a tax reform in Portugal with 'cleaner' industries benefiting the most at the expense of carbon-intensive ones, determining positive performances for both the economy and the environment.

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).

Recent quantitative studies substantiated the positive effect of policy on influencing 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. Along the same lines, Lucena-Giraldo et al. (2022) quantitatively assessed that policy affects firms' environmental performance by improving eco-innovating efforts. However, we need studies combining the two complementary fields, measuring inputs from both science and technological innovation and policy directionality to tackle climate change.

While there are plenty of studies inspecting regional technological proficiency to specialise in green technologies (e.g., Santoalha and Boschma, 2021; Montresor and Quatraro, 2020; Wang and 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 and Rohracher, 2012). Based on the literature, the alignment of science and technological innovation and related policies matters. Therefore, our study investigates the directionality of scientific and technological regional ecosystems and sub-national policy interventions. Our analysis is conceived to provide quantitative empirics to the following research questions:

1. *How have the EU regions been aligning their STI and policy interventions towards Climate Change?*
2. *Are place-specific drivers to explain their alignment?*
3. *Have the EU regions most exposed to climate change-led disaster been aligning their endeavours regarding STI and policy to tackle climate change?*

Despite the critical importance of the regional level for understanding challenge-oriented R&I policy, research on the directionality of regional R&I ecosystems and policy interventions remains limited. This study aims to fill this gap by examining how scientific and technological regional ecosystems and policy interventions influence each other using the RE-SCORE index (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 five EU member states. Such an extensive research design complements case study analyses conducted to assess the alignment of missions (see Parks, 2022). Here, the analysis highlights the strategic intelligence needed to couple the two regional ecosystems with knowledge about the exposure to natural risks generated by climate change.

4. Materials and methods

This paper innovates the literature by shedding light on the geography of regions ready to tackle today's most pressing societal challenge: climate change. The analysis hinges on the RE-SCORE index, which combines regional data about the directionality from Science and 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: France, Germany, Italy, Poland, and Spain. Our study is conceived in three steps to address the research questions:

1) We process empirical data to depict a geography of regional readiness to tackle climate change using the RE-SCORE index approach.

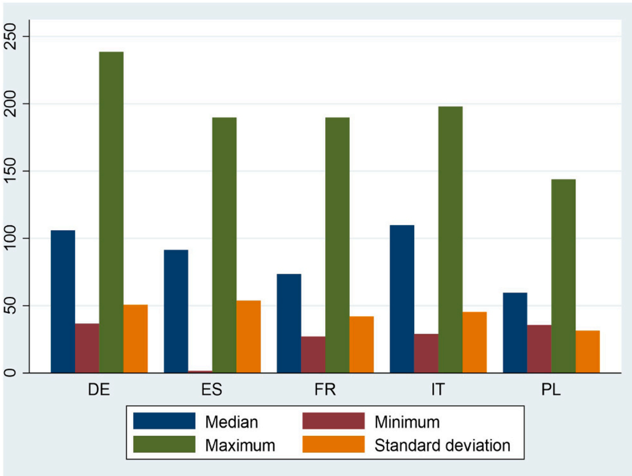

Fig. 1. RCC by country: median, mean, minimum and maximum. Source: Authors'own estimation. Note: RCC refers to the 'Readiness to tackle Climate Change' index.

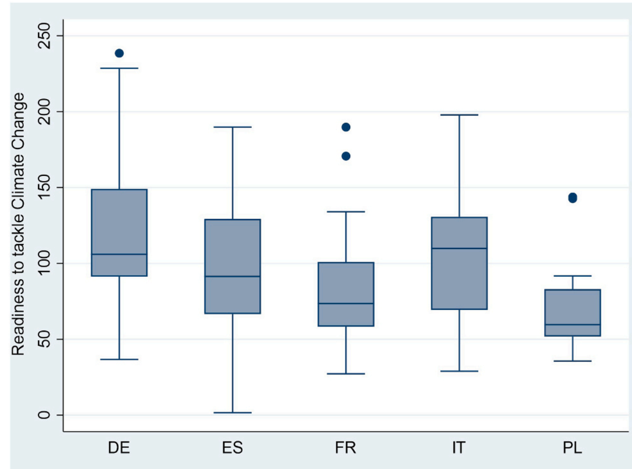

Fig. 2. Box plots RCC by country. Source: Authors 'own estimation.

2) We assess the relationship between the readiness to tackle climate change and regional characteristics.
3) We address the geographical 'problem-solution convergence', investigating whether the EU regions most at risk of being affected by climate change are also the ones most ready to target climate change through an aligned combination of R&I and policy efforts.

The measurement of the regional readiness to tackle climate change follows the methodological approach developed by Cappellano et al. (2022) for Italian regions but expanded to other EU regions and restricted to climate change, as it is notably the most crucial societal challenge of our time. Therefore, we renamed the index as 'Regional Readiness to Tackle Climate Change' (RCC). The selected countries are the five largest EU member states, France, Germany, Italy, Poland and Spain, where most inter-regional disparities are expected. While Italy has a strong, longstanding and well-known North-South divide, the other selected countries have more articulated geographies. For instance, Germany has the longstanding challenge of post-reunification, while France has a traditional dichotomy between Paris and the rest of the country. Following Cappellano et al. (2022), the RCC combines data from KNOWMAK, Bachtrögler et al. (2021) and the European Commission's Horizon dashboard, as described in Table 1.

Data are retrieved from different sources, aggregated at the same regional unit (NUTS-2), and normalised by population for the selected period from 2009 to 2016. Second, 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.

We acknowledge that the different variables used in the index cover different periods, however, there are several reasons to support our choice. The first one is for complementarity and longer time coverage. By combining different periods, we can cover a longer period and increase the stability of our indicator. Second, we are constrained by the availability of data. There is a time lag in terms of data availability from KNOMAK, mainly due to the characteristics of patent data. This lag is due to the time needed for patent offices to process, publish, and then incorporate the data into their databases. The typical time lag is 3 years. On the other hand, data on the specialisation of EU funds in climate change actions are not available before the 2014–2020 programming period, making it impossible to start the series before then. Third to avoid overlap and reverse causality. As Cohesion Policy and Horizon 2020 may influence patent applications and publications, we decided to include a period for patents and publications that refer to a period before the implementation of Cohesion Policy and Horizon 2020 funds in 2014–2020. Even if these funds refer to the 2014–2020 programming period, the implementation of Cohesion Policy started later and more intensively in 2016. Furthermore, the impact on patents and publications is not immediate and may occur with a time lag. To complement this last point, the specialisation of patents and publications tends to be less time-varying in the short term, e.g. the number of patent applications in the field of climate change in one year is highly correlated with the number of patent applications in the previous year.[3]

5. The index of regional readiness to tackle climate change (RCC)

Fig. 1 presents the descriptive statistics of the regional RCC values observed for each selected country. Poland (PL), France (FR), and Spain (ES) report the lowest median value, while Germany (DE) and Italy (IT) report the highest. The minimum regional value recorded is in Spain, whereas the highest is in Germany. The box plots (Fig. 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 Fig. 3.

The RCC performances across the Member States assessed reveal a new geography far less straightforward than expected (Fig. 3). 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. However, several other regions in the same category did not achieve similar RCC performance.

Similarly, German regions do not respect the historical trend between the Western and Eastern parts of the country. While Freiburg (DE13) matches the high innovation leader position with remarkable RCC performance, Brandenburg (DE40) surprisingly overcomes many other German regions. Against all odds, Germany shows a relatively new North-South divide: coastal regions underperform, with the notable exception of Schleswig-Holstein on the border with Denmark. Instead,

[3] Results of correlation coefficients available upon request.

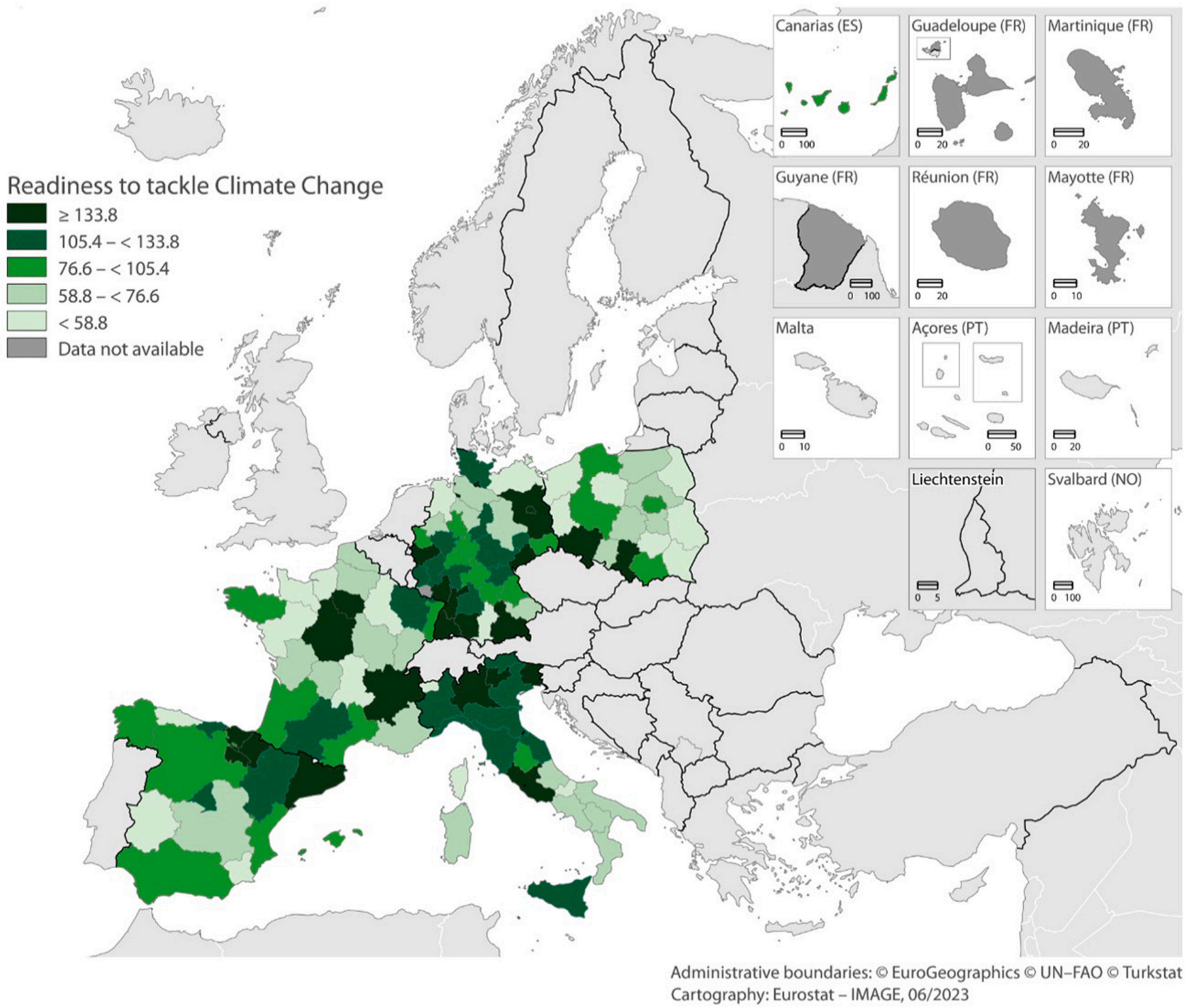

Fig. 3. Geographical distribution of the RCC indicator. Source: Authors' own elaboration.

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 relatively high performances.

The usual East-West divide in Poland is only partially emerging in the southern part. Furthermore, the two regions 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 of regional readiness

To estimate the empirical relationship between the region's readiness to tackle climate change (*RCC*) and the degree of disaster risk they face (*RISK*), we use the model expressed in Eq. (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 regional degree of air pollution, including the greenhouse gas emissions (GHG) in the model. Indeed, we expect that most polluting regions may be influenced to invest 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 the Appendix.

As our dependent variable measures the average regional readiness to tackle climate change in the period 2009–2020 (as described in the 4th section), 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 2010, as this is the first year with available data.

Taking the logarithms[4] of (1), we obtain Eq. (2), which also includes

[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.

Table 2
Explanatory variables description and data source.

Variable	Description	Source
RISK	Level of risk projections of combined 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 from 2022 onwards. The combined risk level corresponds to the average of three types of disaster risk levels.	European Commission's Risk Data Hub, 2024
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, following a similar approach than Aghion et al. (2005) and scientific literature on the relationship between technological progress and productivity (see e.g. Fagerberg, 2000; Carree, 2003)	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)

a country dummy (δ_i) and an error term (ε_i). Considering the nature of the dependent variable, Eq. (2) is estimated using a Pooled OLS.

$$\ln RCC_i = \beta_0 + \beta_1 \ln RISK_i + \beta_2 \ln GHG_i + \beta_3 \ln RD_i + \beta_4 \ln TA_i + \beta_5 \ln AG_i + \beta_6 \ln IQ + \delta_i + \varepsilon_i \quad (2)$$

The primary assumption behind our model (2) is that regions are pushed to re-direct innovation and institutional efforts to fight climate change due to the socio-economic losses or damages they face today and in the future. Nonetheless, regional characteristics may also affect the directionality. For instance, agglomeration economies may be conducive to complex knowledge (Balland and Rigby, 2017). The quality of government may shape regional innovative performance in the EU Regions (Rodríguez-Pose et al., 2014). Innovation inputs like the R&D stock are

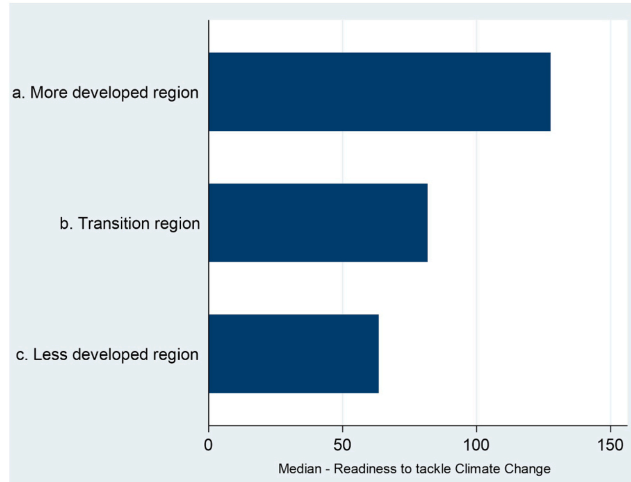

Fig. 4. Median RCC by region categories (Cohesion criteria 2021–2027). Source: Authors' own estimation.

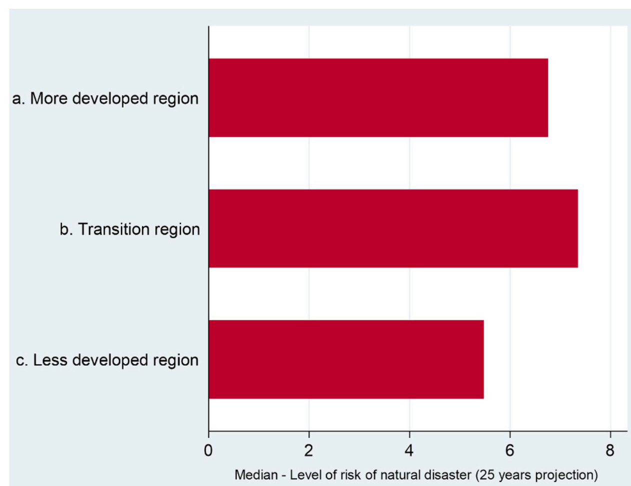

Fig. 5. Median of the risk (estimated over 25 years) by region categories (Cohesion criteria 2021–2027). Source: Authors' own estimation.

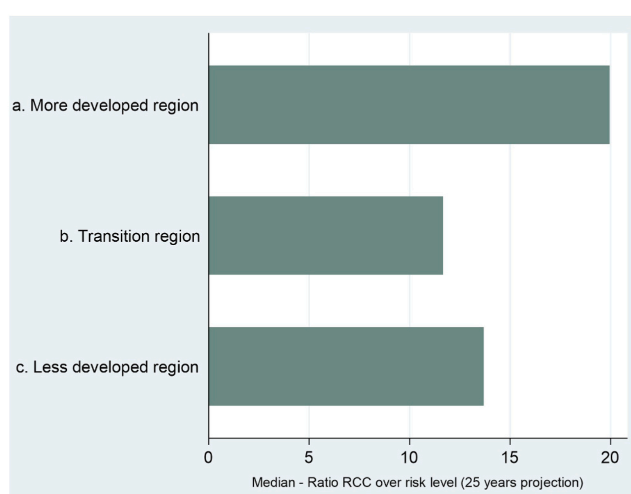

Fig. 6. Median RCC over risk by region categories (Cohesion criteria 2021–2027). Source: Authors' own estimation.

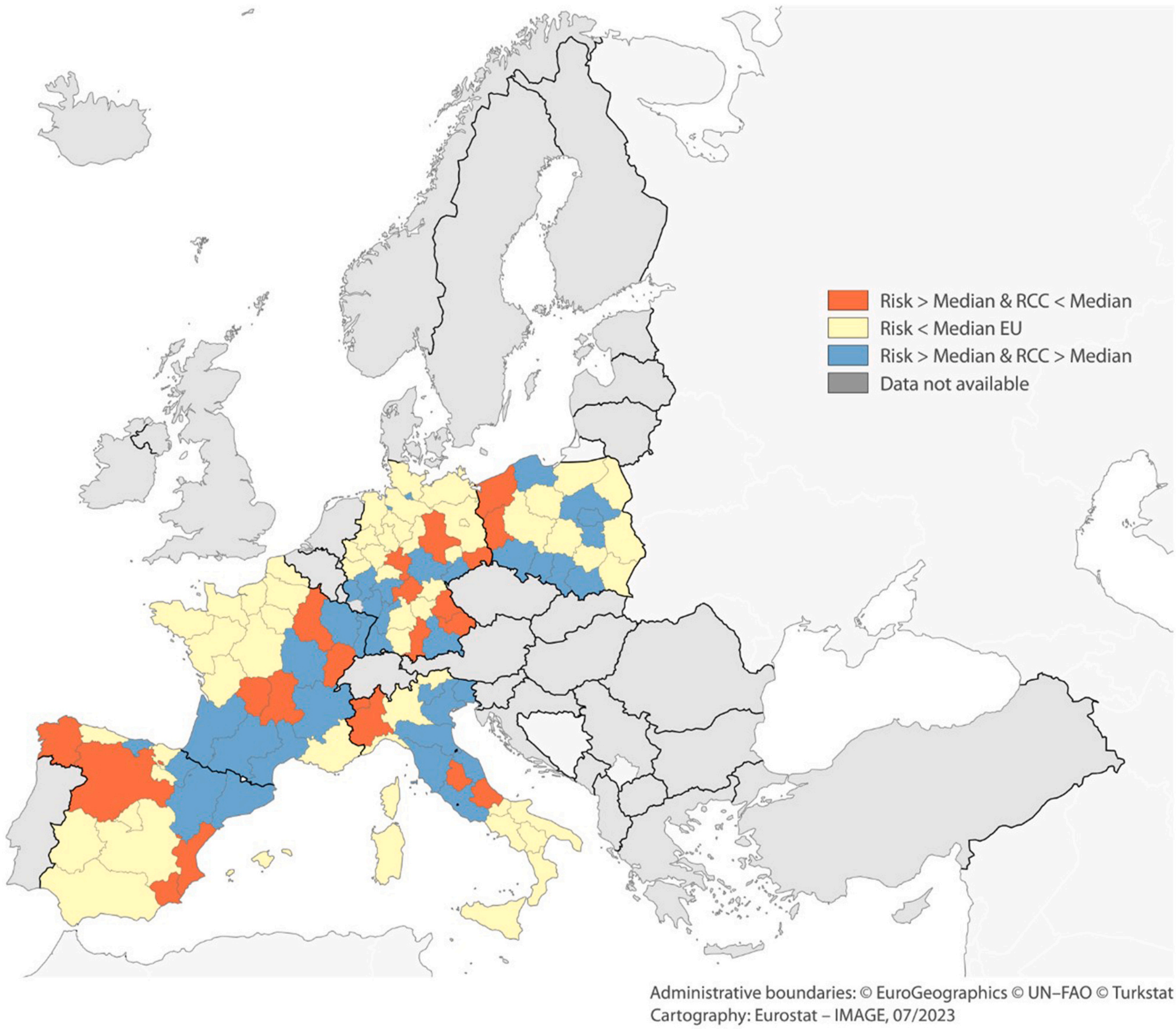

Fig. 7. Classification of regions by the level of risk to natural disasters and their readiness to tackle climate change face to within country median. Source: Authors' own elaboration.

also preconditions for developing and concentrating innovation activities in a few key regions (see Florida et al., 2017).

Fig. 4 and Fig. 5 report the median of the RCC indicator and the median of the disaster risk projection by region category based on the classification of the regions under the 2021–2027 Cohesion policy. Fig. 4 shows that more developed regions have higher RCC values, whereas, according to Fig. 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 (Fig. 6), we observe that more developed regions appear more ready to tackle climate change effects than transition and less developed regions.

Figs. 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 Fig. 7) show lower values vis-à-vis the sample median (in red in Fig. 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 intranational 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.

7. Results: higher economic development and climate risks drive regional readiness

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 projections of combined disasters (coastal floods, river floods and landslides), where risk is defined as the potential loss or damage to society after an expected exposure of 2, 10 or 25 years (respectively, in column 1, 2 and 3 from 2022 onwards). The validation tests reported at the bottom of Table 4 demonstrate that the model has a significant overall fit and does not suffer from omitted variable bias. The results are not biased by collinearity issues (See Appendix A, Table A2), and robustness checks demonstrate the stability of the results after adding or removing explanatory variables (Appendix B, Table B1).

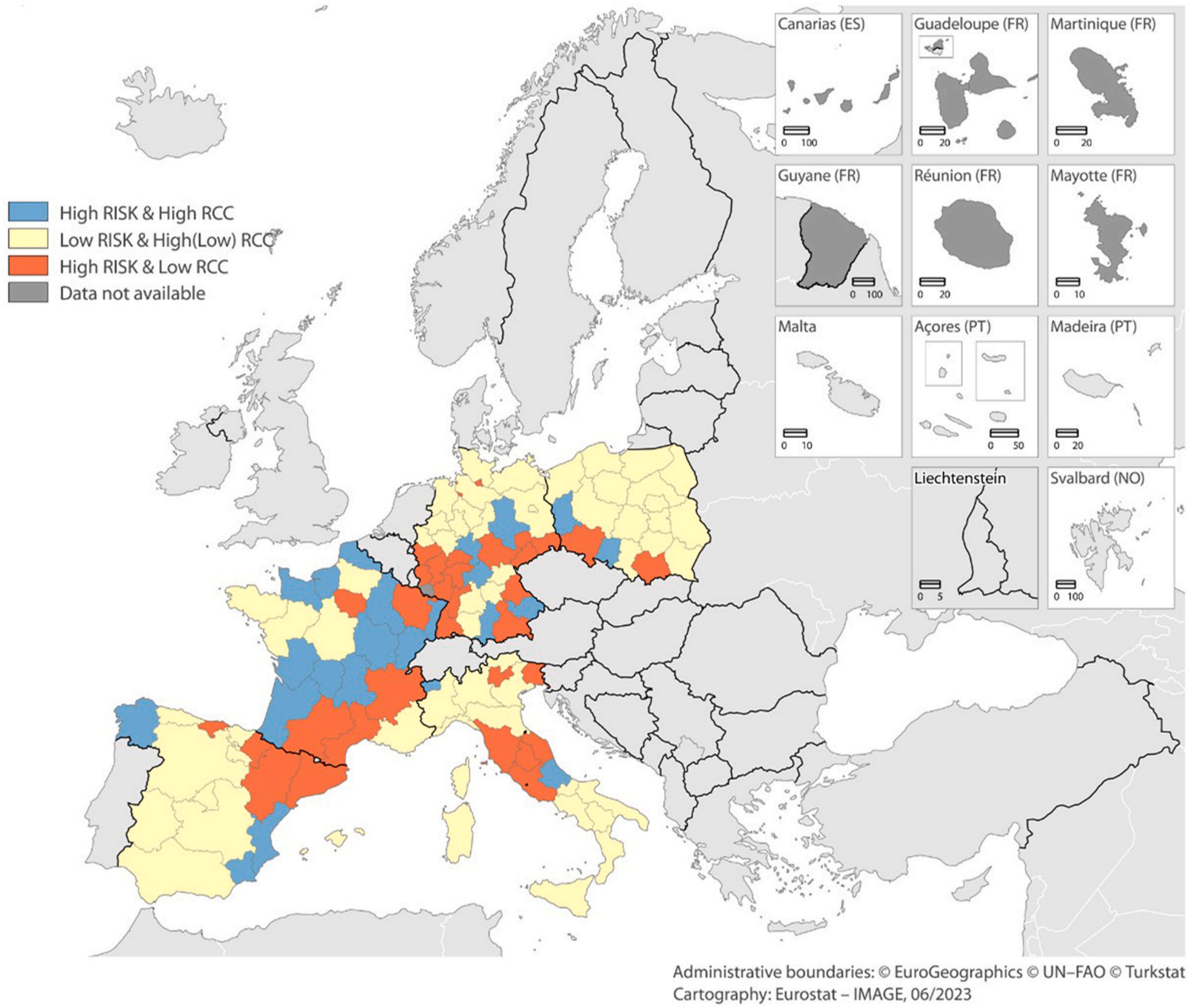

Fig. 8. Classification of regions by the level of risk to natural disasters and their readiness to tackle climate change face to EU sample median. Source: Authors' own elaboration.

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

Country	Risk (25 years projection)	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

The coefficients of the variable risk projection 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 in the regions dealing with climate change. This result is 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 medium and long term (0.234). The z-test also shows that the different coefficients are not statistically different.

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

Note: Risk projection for 25 years. Category of regions refers to Cohesion Criteria for the programming period 2021–2027.

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

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: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

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) positively influences climate adaptation technologies.

Agglomeration economies, measured by the concentration of highly skilled workers in a region, are positively associated with higher values of readiness to tackle climate change. This result confirms the advantages of agglomeration economies (i.e., knowledge absorption, spillovers and transfers) for industries located in regions with higher directionality towards societal challenges. Furthermore, it suggests that skilled human capital is more likely 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. 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.

Based on our findings, we can draw three main lessons for policymakers. Firstly, caution is needed regarding the geography of readiness to tackle climate change because critical territorial imbalances exist. Further territorial imbalances should be prevented because less developed regions with higher climate change-caused risks have lower readiness, making them even more vulnerable.

Secondly, public policy should award the regional intelligence which emerged to connect higher levels of climate-change risks with higher levels of preparedness in the regions dealing with climate change. This sense for "strategic intelligence" should be shared with other regions through peer-learning programmes.

Thirdly, the talented workforce is positively associated with higher values of readiness to tackle climate change. Therefore, EU regions investing in training, attracting, and retaining educated workers can better their knowledge and skills into assets to strengthen their readiness to tackle climate change.

8. Conclusions

Our research reveals a complex geographic pattern of readiness to address climate change through innovation policy. While some regions, particularly those with strong economies, research capabilities, and higher exposure to climate risks, are well-positioned to lead the way, others, especially less developed regions facing high climate risks, lag behind. These findings highlight the need for tailored strategies to ensure all regions contribute to and benefit from climate action, integrating the regional dimensions into the broader debate on orienting innovation policies to tackle societal challenges.

We addressed three research questions. First, we showed that the readiness to tackle climate change does not follow the usual geographies. For instance, the well-known Italy's North-South divide, or Germany's East-West differences are much more articulated when it comes to discuss their R&I policies' alignment to tackle climate change. Second, we unfolded the place-specific drivers that affect the regional capacity to align their R&I and policy endeavours to tackle climate change: the combination of risks, R&D intensity and human capital concentration.

Third, regions at higher risks are more 'ready' to engage with this societal challenge. Our findings provided evidence of interregional dissimilarities in adopting a mission-oriented approach to combating climate change.

Concerns emerge for two categories of regions: advanced regions with lower risks are less likely to mobilise for climate change, potentially weakening a Europe-wide effort. Less developed regions show lower readiness values to tackle climate change. Policymakers should be aware of these differences to ensure 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 encompassing diverse regional realities, ensuring a holistic and practical 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.

As a general assumption, we recognize the spatial mismatch between the origin of emissions – the regions that most pollute – does not necessarily correspond with the geographical impact of climate changes – the areas mostly affected by climate change-led disasters. Therefore, regions that engages in tackling climate change locally through promoting R&I policies will not necessarily witness their local payoff. However, it is interesting to understand if the EU regions most exposed to climate change-led disasters have been more active in promoting challenge-oriented innovation policies. This is another element of novelty as no study fills this gap in the academic literature.

While our analysis offers valuable insights, it is essential to acknowledge its limitations. Our focus on large EU member states restricts the scope of our findings, and the reliance on funding data as a proxy for policy direction limits our understanding of local policy dynamics. Additionally, our focus on scientific and technological innovation overlooks other forms of innovation, and we cannot account for the potential impact of behavioural changes at the regional level.

Future research should expand geographically to include all EU regions and explore how regional readiness to address climate change has evolved over time. Understanding the interplay between pollution sources and climate impacts is also crucial. By addressing these limitations, we can develop a more comprehensive picture of regional capacities and challenges in the fight against climate change.

Ultimately, our findings emphasise the importance of considering regional disparities when designing and implementing climate policies. By acknowledging and addressing these differences, policymakers can foster a more equitable and effective response to this global crisis.

CRediT authorship contribution statement

Nicola Francesco Dotti: Validation, Writing – review & editing. **Anabela Marques Santos:** Data curation, Methodology, Visualization, Writing – review & editing. **Francesco Cappellano:** Conceptualization, Investigation, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests. Francesco Cappellano reports financial support was provided by National Agency for Academic Exchange

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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	1922,885
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)	-

(*continued on next page*)

Table B1 (*continued*)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
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
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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