What determines drivers and barriers of the implementation of Circular Economy measures at regional level?

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Abstract

This paper analyses regional drivers and barriers regarding the implementation of circular economy actions carried out at the EU level. Using data from Flash Eurobarometer 498, we gather regional data on circular economy actions taken by firms in European regions in 2021. We analyse drivers and barriers from this dataset by focusing on both existent spatial heterogeneity and the perspectives of the engagement in these actions. Our results shed some light on the identification of regional contexts that may boost / restrict the implementation of circular economy strategies.

Keywords: Circular economy, drivers, barriers, regions, European Union

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1. Introduction

Circular economy (CE) initiatives are considered key strategies for contributing to energy and ecological transition and achieving sustainable development goals. However, despite the importance policy-makers place on these strategies (European Commission, 2020; Hartley *et al.,* 2023), their implementation has been slow in practice, and, more importantly, little is known about what drives and hinders them. Therefore, further research is needed to identify the optimal conditions that maximize drivers and minimize barriers.

In view of the huge complexity of current production systems and international linkages of value chains, implementation of CE actions requires strong intervention by public authorities to provide the institutional framework, infrastructures, and material conditions required by firms. A key point is the identification of the type of public administrations better suited to take such an active role in CE promotion. In this respect, those operating at the regional level are better placed to lead this process, as the regional dimension fits perfectly with the main principles of the CE (Arauzo-Carod *et al*., 2022; Silvestri *et al*., 2020) because the circular structure of reusing, remaking, and recycling implies a close spatial connection among all these stages (Tantau *et al*., 2018). The required spatial proximity also implies the need for coordination, which requires common governance (Mhatre *et al*., 2021). This is why regions (and their institutions) must play a significant role in the CE (Sotarauta *et al*., 2021).

Although there is growing awareness of the pivotal role of regions in facilitating the shift from linear to circular systems, an overview of contributions on the spatial dimension reveals that the implementation of CE strategies on the regional level remains in its infancy (Arsova *et al*., 2022). Indeed, most research focuses either on countries or on firm-level case studies, while analyses at the regional level are still quite scarce due to the absence of a robust theoretical framework (Bourdin and Torre, 2025) and a lack of adequate data (Arsova *et al*., 2022; Bianchi *et al.,* 2023). This is an important shortcoming, since CE initiatives should be (mainly) designed and implemented at the regional level in view of the characteristics of these actions and the necessity to avoid negative externalities of current offshoring strategies (Obersteg *et al*., 2019).

Against this background, this paper aims to analyse the spatial distribution of CE actions undertaken by SMEs and to understand why certain regions have fallen behind in CE implementation. To this end, it addresses the following research questions: 1) What are the main drivers that facilitate CE implementation at the regional level within the EU? 2) What are the key barriers that regions face when implementing CE practices? To answer these questions, we use the European Commission's Eurobarometer Survey 498 on “Small and Medium Enterprises, Resource Efficiency and Green Markets”, which provides the opportunity to examine regional differences in CE progress. We enlarged this dataset with additional European regional databases, providing information on a broad range of factors that may drive or hinder CE actions.

We contribute to the emerging literature on the spatial dimension of CE in several ways. First, the literature has been particularly reliant on the national context rather than on other geographical contexts. However, this paper enhances previous research by examining over 200 European regions, offering new insights into the current level of CE implementation across regions. Second, of the few regional contributions that exist, most are qualitative approaches based on case studies, one of the main gaps in the CE literature at the regional level being the lack of empirical work (Arsova *et al*., 2022; Bourdin and Torre, 2025). This is why we use robust spatial econometric methods (i.e., Geographically Weighted Regression, GWR) showing that the effect of CE determinants varies across regions. Third, to capture the multi-dimensional nature of the CE, we use different CE indicators grouped into three circular strategies (*Reduce*, *Recycle*, and *Redesign*), which enables us to identify both differences and similarities in drivers and barriers. This will in turn facilitate the design of policy tools to boost circularity measures carried out by EU firms and will then facilitate sustainable transition to achieve EU targets of climate neutrality by 2050.

The remainder of the paper is organised as follows: section 2 consists of a literature review, section 3 discusses the data set and methods, section 4 analyses the main results and section 5 concludes and provides some policy implications.

2. Background and literature review

2.1 EU policy framework

The European Commission is undoubtedly one of the institutions most committed to incorporating the principles of the CE into its political agenda (Alberich *et al*., 2023; Hartley *et al.,* 2023). Initial steps towards circularity began in 2015 with the first European plan, “Closing the Loop: An EU Action Plan for the Circular Economy” (European Commission, 2015). This plan emphasised minimising waste generation and extending the life of products, materials, and resources. The European Union (EU)’s commitment to circularity was reinforced in 2019, when it became one of the core pillars of its Green Deal policy. This commitment was expanded in March 2020 with a renewed action plan aimed at accelerating the transition towards a regenerative growth model that would contribute to increasing the use of recycled materials and reducing the consumption footprint (European Commission, 2020). Now, as the EU embarks on a new political and institutional cycle with the objective of strengthening the continent’s economy and competitiveness, circularity continues to shape EU policy with the new Commissioner facing the challenge of gradually establishing a Circular Single Market (Dragui, 2024; Letta, 2024).

Nearly a decade after the first European CE action plan, the concept of CE appears to have solidified, with a clearer set of core principles, objectives, enablers, and beneficiaries (Kirchherr *et al*., 2023). However, despite significant efforts involving legislation, funding, and R&D, progress towards circularity remains modest, putting the achievement of long-term climate goals at risk (Castillo-Díaz *et al*., 2024; Morató and Jiménez, 2023). In the early stages, Member States have commonly emphasised waste management over circular product design or sustainable production processes, but a shift is emerging with a growing emphasis on innovation (De Pascale *et al.,* 2023).

Implementing circular strategies is both a complex challenge and a significant opportunity, as it requires the coordination of diverse policy areas (such as energy, climate, industry, innovation, agriculture, employment) and involves a wide range of stakeholders (Arsova *et al*., 2022; Chembessi *et al*., 2025). The EU’s latest Circular Action Plan frames this transition as a “systemic, deep, and transformative” process that relies on effective cooperation at all levels, from the EU itself to national, regional, and local levels. In this regard, Bourdin and Torre (2025) argue that realising the CE's full potential requires integrating spatial and territorial dimensions into its conceptual framework, which have been largely overlooked.

While the Circular Action Plan constitutes a common framework that underpins the various approaches of the Member States, the final selection of the implemented measures lies in the hands of national and regional governments, along with their intensity and scope. This flexibility has led to a fragmented policy landscape, exacerbating differences in circularity progress across the EU (Domenech and Bahn-Walkowiak, 2019; Silvestri *et al*., 2020). In this respect, Bourdin and Torre (2025) emphasise that regional CE initiatives are often less developed and structured than national policies, due to gaps in institutional frameworks and resources, which tend to be more robust at the national level. Despite the critical potential of regions, most competencies are allocated to member states, relegating regions to implementers of national policies rather than policy creators.

2.2 Drivers and barriers

Recent research has increasingly focused on identifying the challenges and constraints associated with the implementation of the CE, primarily through theoretical and conceptual frameworks, literature reviews, and case studies, but with limited support from empirical evidence (see, among others, Arsova *et al*., 2022; De Jesus and Mendonça, 2018; Govindan and Hasanagic, 2018; Kirchherr *et al*., 2018; Mehmood *et al*., 2021; Munaro and Tavares, 2023; and Ouro-Salim and Guarnieri, 2023).

Overall, the literature has identified a set of factors that favour the implementation of CE measures (drivers) and others that hinder it (barriers). To synthesise an extensive list of drivers and barriers, Tura *et al*. (2019) provide a holistic view through a systematic characterisation that organises the factors into seven specific categories: *i)* technological knowledge (new technologies available that enable the use of the production process in terms of use of recycled materials, redesign, and waste reduction), *ii)* organisational (includes knowledge to reorganise management and resource flows across the production process), *iii)* social engagement (encompasses awareness of sustainability and willingness to pay higher prices for environmentally neutral products), *iv)* institutional (implies a favourable legal and regulatory framework and support policy instruments to share additional production costs linked to the use of waste and recycled materials), *v)* supply chain (includes network support and partners to facilitate circular practices), vi) environmental (concerns about climate change and resource constraints) and *vii)* economic (in regard to new firms and jobs created to implement circular actions). These factors (often acting simultaneously) are widely acknowledged in the literature and have been recently adapted by Aloini *et al.* (2020), Geissdoerfer *et al*. (2023), and others.

Environmental concerns, such as climate change, biodiversity loss and resource limitations, are often presented as key motivators for the CE. In fact, the transition to the CE is frequently seen as a strategic response to global sustainability and economic opportunity, such as job potential, new business models and profits (Bourdin and Torre, 2025; Govindan and Hasanagic, 2018; Tura *et al*., 2019). However, Tura *et al*. (2019) show that social pressure and regulation and legislation play a key role in the transition towards the CE. These results are aligned with earlier research by De Jesus and Mendoza (2018) who, conducting a systematic review, argue that the CE is primarily driven by soft factors, such as social, regulatory and institutional influences.

In contrast, Kirchherr *et al*. (2018) identify significant barriers to the CE, categorising them as cultural (lack of firm or consumer awareness and interest), regulatory (lack of government support caused by weak institutional frameworks), market (lack of market, funding or higher production cost) and technological barriers (lack of know-how, poor quality perception of recycled goods). They stress that the main barriers are cultural, including both the lack of interest from consumers and the business culture. More recently, Grafström and Aasma (2021) highlighted that, while cultural barriers persist, institutional barriers also play an important role in preventing business from fully embracing the CE.

Additionally, there is also evidence of a link between technology and network collaboration among the supply chain partners and circularity. De Jesus and Mendoza (2018) and De Jesus *et al.* (2019) note that transitioning firms from linear to circular business models takes time to change production methods and relies heavily on technological innovation. However, De Jesus and Mendoza (2018) emphasise that availability of relevant technical solutions and financial resources are considered hard barriers to the progress of the CE. Moreover, Ormazabal *et al.* (2018) and Triguero *et al*. (2022) find that knowledge sharing between firms can promote collaborations and reduce supply dependence and risk from global market fluctuations. Nonetheless, Kirchherr *et al*. (2018) stress that a lack of technical skills and capabilities often discourages CE adoption.

Beyond considering the multiple factors that may influence the adoption of circular practices, another significant issue emerges: the need to distinguish between the diverse activities encompassed by the CE. Actions such as reducing, recycling, and redesigning involve distinct processes and strategies, which highlights the importance of adopting holistic approaches that move beyond narrow indicators like material usage or recycling rates (Ghisetti and Montresor, 2020; Triguero *et al*., 2022). Many scholars agree that barriers and drivers can vary significantly, depending on the type of CE strategy involved. For example, García-Quevedo *et al*. (2020) find that firms focusing on redesign strategies perceive more barriers compared to those emphasising reduction, which primarily encounter procedural and administrative challenges.

Overall, these findings underline the dual perspectives with which certain factors can be analysed in the context of enabling or hindering and the need to consider multiple aspects of the CE. Studies also stress that there is no single dominant driver or barrier; rather, the process is shaped by a combination of enabling and limiting factors, which vary according to specific local conditions. This highly context-specific nature is confirmed by Tura *et al*. (2019) and Passaro *et al.* (2023), who found that CE principles in firm-level strategies varied significantly, calling attention to the need for a more nuanced analysis.

Despite ongoing efforts to identify key drivers and barriers, there is a lack of consensus in the literature (Arsova *et al*., 2022; Govindan and Hasanagic, 2018; Kirchherr *et al*., 2018; Passaro *et al.,* 2023). Factors influencing the CE are highly multidimensional, requiring analysis across spatial and industry levels. In this context, these factors are expected to be implemented with a regional scope (i.e., NUTS2), to balance the availability of potential inputs generated by firms and the need to avoid them travelling long distances. As for the industry dimension, an overview of the literature about drivers and barriers of CE measures shows that most contributions refer to particular industries and activities, such as supply chains (Govindan and Hasanagic, 2018), food supply chains (Ouro-Salim and Guarnieri, 2023), agri-food supply chains (Mehmood *et al*., 2021), leather industries (Moktadir *et al*., 2018), automobile (Agyemang *et al*., 2019), mining (Osei *et al*., 2023), construction (Munaro and Tavares, 2023), and tourism accommodation (Santos *et al*., 2023), among others. However, given the diversity in technologies, raw materials, and processes, this paper adopts an aggregate approach to avoid overwhelming complexity.

At the regional level, the literature is dominated by case studies and reviews that often offer a narrow perspective. For instance, Sani *et al*. (2021) limit their analysis to a few factors (technological, legal-regulatory, and financial) when examining CE drivers in Emilia-Romagna (Italy). Lechner *et al*. (2021) explore the specific drivers of network collaboration and public funding schemes in the circular repair strategy in the city of Graz (Austria). They argue that local government acting as network organizers, along with adequate policy frameworks, can play a key role in supporting the development of CE initiatives. Similarly, Bezama *et al*. (2019) analyse the drivers of bioeconomy at the regional level through the lenses of resources, collaborators, and neighbouring actions. They emphasise the importance of fostering collaboration among clusters and supply chain networks to enhance circularity within the bio-based industrial sector. These insights align with the findings of Bourdin and Jacquet (2025), who examine the barriers and drivers of CE implementation, albeit focusing specifically on French cities and regions. Their study identifies partnership and the development of collaborative networks, along with political leadership with strategic vision, as key drivers of the CE. Conversely, they highlight financial constraints, fragmented governance, and the lack of monitoring and evaluation indicators as major barriers.

Fromhold-Eisebith (2024) builds bridges between the literature on regional innovation and the specific demands of the CE. Empirical evidence from the Aachen region (Germany) shows that the adoption of circular practices is hindered by structural shortcomings in local innovation systems — such as a lack of technology transfer, inter-firm collaboration, institutional leadership, and human capital. Moreover, the author emphasizes that the circular transition cannot be achieved solely through technical fixes or general policy measures, highlighting instead the need to foster social innovations that involve citizen participation and cultural change.

Other regional studies stress the importance of human capital for putting the CE into practice (Buyukyazici and Quatraro, 2025; Martin, 2025). These studies highlight the diverse skill requirements involved, as the CE encompasses a wide range of economic activities. According to Buyukyazici and Quatraro (2025), core CE activities—such as collection, recycling, repair, reuse, and maintenance—rely more heavily on physical and psychomotor skills than on advanced technical knowledge. In contrast, enabling CE activities that facilitate innovation processes (e.g., redesign) require highly complex and knowledge-intensive skills.

These fragmented approaches, while useful to understand specific contexts, often fail to capture the broader structural inequalities that shape CE development across regions (Silvestri *et al*., 2020). In this respect, Barbero *et al*. (2025) contribute to empirical research and confirm that the ability to absorb funds for CE actions is not evenly distributed across EU regions. Their findings suggest that this disparity is closely linked to contextual factors such as institutional quality, labour market conditions, education, and income levels.

While studies on micro- and meso-level drivers and barriers are abundant, macro-level analyses, especially at regional and city levels, are scarce (Arsova *et al*., 2022). The predominant focus on business undermines the significant influence of geographical factors in the CE (Bourdin and Torre, 2025). To address this gap, we provide new empirical evidence on the regional CE transition. Given that CE encompasses a wide range of strategies, analysing it through a narrow set of factors would be overly simplistic. Drawing on prior research, we adapt the framework proposed by Tura *et al.* (2019), which was originally designed for firm-level analysis, to better capture the complexity of CE adoption at the regional level. Our approach is thus multidimensional, integrating institutional, socioeconomic and organizational, environmental and technological and supply chain factors to offer a more comprehensive understanding of the limited uptake of a CE at the regional level.

3. Data and methods

3.1 Data

To determine the level of circularity in European regions, and its drivers and barriers, we gathered a thorough dataset. First, the Flash Eurobarometer Survey 498 on "Small and Medium Enterprises, Resource Efficiency and Green Markets, wave 5" is used to quantify the incidence of the CE in a regional context. This survey was carried out by the European Commission between November and December 2021, comprising 14,158 interviews with SME managers from the 27 EU member states.[1] It is one of the most widely used datasets in environmental studies among European SMEs and has recently been applied to investigate CE concerns (Gomes and Pinho, 2023; Darmandieu *et al*., 2022), as it identifies nine resource efficiency activities directly related to the CE (water reduction; energy reduction; predominant use of renewable energy; saving materials; switching to greener suppliers; minimising waste; selling scrap material to another company; recycling; and designing products that are easy to maintain, repair or use). Following the insights from previous studies (Segarra *et al*., 2024; Triguero *et al*., 2022), we classified the nine CE actions into three circular strategies (Reduce, Recycle and Redesign) to disentangle the idiosyncrasy of each one (see Table 1). Overall, most firms involved with CE actions focus on waste, whilst eco-innovation, eco-design, and redesign do not attract as much attention, but the actions undertaken during the 2021-2027 period seem to be succeeding in reversing this trend (Morató and Jiménez, 2023), which is why we want to focus on these three typologies.

[INSERT TABLE 1 ABOUT HERE]

Although this survey is not specifically designed to examine regional aspects of circularity, it includes information on the location of company headquarters, which

[1] Previous studies have previously used the survey at regional level (see López-Bazo, 2021). The average number of observations used to compute the indicators in the set of regions used for the analysis is 67, whereas in the median region there are 43 observations. In less than 25% of the regions, the number of responses is lower than 19, whereas in less than 75%, the number of responses is lower than 87. In any case, it should be mentioned that some robustness checks were performed to assess the influence of the inclusion of regions with fewer responses. In general, the main conclusions derived from the results remained unaltered when these regions were excluded from the analysis.

makes it possible to compute the results at the regional level.[2] [3] Our choice has been to focus on firms' actions in order to measure CE development in the EU, but there are other alternative indicators focusing not on firms but on the whole of society (i.e., including firms, consumers and governments), such as the one proposed by the European Commission in 2023 consisting of 11 indicators grouped into five groups. While this European monitoring framework is key to tracking the evolution of circularity in the Member States, the scarcity or absence of data in certain cases in subnational contexts significantly hinders the replication of the proposed indicators at the national level (Henrysson *et al.,* 2022). Both theoretical and empirical literature acknowledges that national statistics often provide a picture that is very distant from territorial realities, potentially offering a limited view for public policy decision-makers.

To capture the regional capabilities to engage in CE actions, we calculate a composite Location Quotient (LQ) index that compares the relative specialisation of EU regions in CE actions taken by SMEs in relation to the EU 27 average. The composite LQ is computed in different steps. First, the LQ is computed for each of the nine actions in the CE. The LQ is defined for region *i* and CE action *j* as follows:

$$LQ_{ij} = \frac{\frac{E_{ij}}{E_i}}{\frac{\sum_k E_{kj}}{\sum_k E_k}} \tag{1}$$

E_i where E_{ij} is the number of firms taking the CE action *j* in region *i*, E_i is the total number of firms surveyed in region *i*, while $\sum_k E_{kj}$ is total number firms in all regions (EU 27) reporting action *j* and $\sum_k E_k$ is the total number of firms surveyed in all regions in EU 27. An LQ_{ij} > 1 means the proportion of firms in region *i* doing action *j* exceeds the EU-wide proportion, that is clustering of a CE action *j* in region *i* is larger than the European average; hence, the region is specialised in this CE action.

Among its advantages, LQ is highly data-efficient—requiring only counts of firms by action and region—and immediately interpretable: regions with LQ > 1 clearly stand out as CE "hotspots." Its flexibility allows separate evaluation of "Reduce," "Recycle," and "Redesign" strategies. By comparing each region's share of firms undertaking a given CE practice (from the nine activities in Flash Eurobarometer 498) to the EU-27 average, the LQ normalizes for regional survey totals and highlights where CE engagement is unusually concentrated.

Once the indices for each CE action have been obtained, they are arithmetically aggregated for each of the three strategies (LQ_Reduce, LQ_Recycle and LQ_Redesign) and in a global index that arithmetically aggregates all of them applying equal weights to each composant (LQ_CE)[4].

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[2] Note that other studies have successfully used Flash Eurobarometer data for regional-level analyses—for example López-Bazo (2021).

[3] The regional level used in this paper (208 regions) is NUTS1 for Germany and NUTS2 for the rest of countries.

[4] LQ_CE_j, for all CE actions in region *j*; LQ_Reduce_j, for CE actions including waste, water and material reduction; $LQ\_Recycle_j$, for CE actions including recycle and reusing material or waste and using predominantly renewable energy; and $LQ\_Redesign_j$, for CE actions including design of products that are easier to maintain, repair or reuse.

[INSERT FIGURE 1 ABOUT HERE]

Figure 1 illustrates the regional distribution of SME-driven CE specialization across Europe. Specifically, for the aggregate measure (LQ_CE), Figure 1 shows that there are clear regional disparities, as values differ considerably between regions performing very well (e.g., most Spanish, as well as Swedish and some Benelux regions) and regions with low performance in countries like Portugal, Ireland or in some French regions. As for Spain, for instance, our measure of the CE is consistent with data sources that indicate that the situation of the CE in Spain has improved considerably after the implementation of the National Circular Economy Strategy in 2020 (Morató and Jiménez, 2023). For a detailed analysis of leading and lagging EU countries see Mazur-Wierzbicka (2021), who pinpoint Germany, Belgium, Spain, France, Italy and the Netherlands as the leading countries in terms of CE actions. Silvestri *et al*. (2020) detected that the top 15 best performing regions (i.e., static indicator) are in France, Germany, The Netherlands, and Belgium. Based on the dynamic indicator, along with some regions in France, Belgium, Spain and Austria, the best CE performance is achieved by regions in Eastern Europe. Similarly, Castillo-Díaz *et al*. (2024) show that Germany led the CE ranking, while Italy occupied second position. France, Belgium, Spain, and the Netherlands completed the top six most advanced countries, and Luxembourg, Malta, Estonia, Denmark, and Finland ranked at the bottom.

3.2 Econometric methodology

We estimate the implementation of CE actions in a region as a function of the specific regional characteristics:

$$Y_{ij} = \beta X_j + \varepsilon_j \qquad (2)$$

where Y_j is the dependent variable, the location quotient of CE Actions in 2021 in region j (defined as four different dependent variables: *LQ_CE, LQ_Reduce, LQ_Recycle, LQ_Redesign*), X_j is a matrix containing all independent variables plus an intercept, and ε is the error term.

The explanatory variables used in the model to understand the development of CE actions are categorised into four vectors: Institutional, Socioeconomic and Organisational, Environmental, and Technological and Supply Chain, adapted from the classification proposed by Tura *et al.* (2019). Each vector captures distinct dimensions influencing CE practices, providing a comprehensive framework for analysis. To do this, we enlarged the Flash Eurobarometer Survey 498 with regional information from the Regional Innovation Scoreboard (RIS), the European Quality of Government Index (EQI) surveys and Eurostat (see Table 2).

[INSERT TABLE 2 ABOUT HERE]

The "Institutional" vector includes *GovernmentQuality*, an index reflecting citizens' perceptions of corruption, service quality, and impartiality in essential public services. Regions with high government quality are expected to demonstrate stronger adoption of CE actions due to efficient governance and trust in institutions (Agovino *et al*., 2020). The *NorthSouth* variable distinguishes southern European regions (e.g., Portugal, Spain, Italy and Greece) from others, reflecting potential disparities in structural readiness for CE initiatives, in a similar way that for other indicators that identify a North-South divide. Specifically, Southern regions may face challenges such as weaker governance or economic constraints, which could negatively impact CE development (Alonso-Almeida and Rodríguez-Antón, 2020). Overall, variables included in the “Institutional” vector co-determine how quickly CE business models can be scaled and, therefore, CE actions be implemented.

The “Socioeconomic and Organisational” vector emphasises human capital and regional characteristics. *Employment_KIS* captures employment in knowledge-intensive sectors, expected to positively influence CE actions by supporting innovation and expertise-driven practices (Arsova *et al*., 2022).[5] Similarly, *Digitalskills* measures advanced digital capabilities, critical for implementing resource optimisation technologies and fostering CE innovations (Mehmood *et al*., 2021). Social engagement is proxied by the population involved in lifelong learning, as higher education is associated with greater knowledge of green practices and increased awareness of environmental protection (Avdiushchenko and Zajaç, 2019). Finally, *Urban*, a dummy variable for urban regions, suggests that urban areas are better positioned to implement CE actions due to higher infrastructure density and innovation ecosystems (OECD, 2020). All these variables considered together try to measure the human and organisational capacities to innovate and implement CE practices.

The “Environmental” vector also plays a pivotal role. The variable *Heating_days*, reflecting climate-related energy demands, captures regional differences that may shape specific CE challenges and opportunities, such as energy efficiency measures (Davies *et al*., 2024), as colder / milder climates may imply different environmental actions thus leading to the realisation of particular CE actions. The “Technological and Supply Chain” vector includes variables like *RD_public* and *RD_private* to measure public and private R&D expenditure, as well as *Processinnovation*. They are expected to positively drive CE actions through innovation and technological advancement (Scarpellini *et al*., 2019). *Cooperation*, measuring SME collaboration rates, highlights the importance of partnerships in knowledge sharing and sustainable solution development, further reinforcing the supply chain’s role in advancing circularity (Govindan and Hasanagic, 2018). Altogether, these variables can be understood as innovation enablers, as they capture structural conditions allowing CE solutions to be designed, tested and diffused.

Together, these variables provide an integrated perspective on the drivers and barriers shaping CE actions, enabling the identification of region-specific strategies to foster sustainable development.

The fact that all variables may have some spatial dependence could render the standard estimation methods inappropriate, since the assumption of non-dependence between cross-sectional observations is presumably not satisfied. Therefore, it is also necessary to use spatial econometric methods to tackle these spatial issues. This econometric strategy represents one of the key contributions of the paper, as much of the existing CE literature has overlooked the spatial dimension of this phenomenon, potentially introducing significant bias into the econometric estimations.

[5] Beyond technical work, some specific activities of the circular economy are also linked to a type of ‘dark’ work as in the case of that resource recovery is a new form of dirty work, located in secondary labor markets and reliant on itinerant and migrant labor (Gregson *et al*., 2016).

In this respect, Geographically Weighted Regression (GWR) is an increasingly popular tool since Fotheringham *et al*. (2002) first implemented it at the beginning of the 2000s. Its main advantage is that it allows spatial heterogeneity and is especially recommended when using many heterogeneous spatial units (e.g., EU regions). GWR estimates separate regression coefficients for each observation, rather than just looking at the mean, as in OLS methods. This procedure makes it possible to obtain spatially varying coefficients, i.e., there are as many β as spatial units, allowing each covariate to have different effects on the dependent variable, in accordance with the location. The main advantage of GWR is its flexibility in terms of addressing spatial non-stationarity. Potential sources of these spatial variations are the inherent instability of the relationships across space (true non-stationarity) or limitations of the model itself (misspecification). Other advantages of GWR include an improved model fit (which allows more accurate predictions), the capacity to identify local patterns which are somewhat hidden when using global models, and a better treatment of spatial autocorrelation. Specifically, parameters in a GWR approach have the following structure:

$$\hat{\beta}_j = \left(X^T W_j X\right)^{-1} X^T W_j Y \quad (3)$$

where $\hat{\beta}_j$ is the vector of parameter estimates for region j, W_j is the diagonal weights matrix for region j, X is the matrix of the covariates, and Y is the vector of the dependent variables. Given that the volume of results is quite large (i.e., specific β coefficients and R^2 for each observation), normally GWR results are displayed through maps rather than tables.

4. Results

The implementation of CE actions is explained in terms of the effects of four vectors of covariates referred to Institutional, Socioeconomic and Organisational, Environmental, and Technological and Supply Chain characteristics. The baseline OLS estimation (see Table 3)[6] shows the existence of two distinct patterns: on the one hand, the overall CE actions and the CE actions about reducing and recycling and, on the other hand, the CE actions focused on redesign. These results support the argument, acknowledged in previous literature (Buyukyazici and Quatraro, 2025; García-Quevedo *et al*., 2020) that distinguishing between the diverse activities encompassed by the CE is essential for understanding its implementation dynamics.

[INSERT TABLE 3 ABOUT HERE]

The econometric results reveal the existence of two separate processes. In this respect, CE strategies included in the first group (i.e., CE, Reduce and Recycle) exhibit similar patterns in terms of their determinants, whilst the second group (i.e., Redesign) seems to be driven by other determinants not included in this estimation. Regarding the first group, we can highlight the negative effect of the percentage of employment in knowledge-intensive activities (*Employment_KIS*) and the percentage of SMEs introducing business process innovation (*ProcessInnovation*), and the positive effects of R&D efforts by private (*RD_private*) and public (*RD_public*) organisations. Also, the

[6] We have checked that there are no multicollinearity problems (see VIF values in Table 3) nor major correlation problems (see Table A.1). We have also carried out a Regression Specification Error Test, which indicates that the models are correctly specified overall and that there is no omitted variable bias.

availability of digital skills (*Digitalskills*) boosts CE strategies, while being in a southern EU region also pushes up overall CE actions and CE Reduce and Recycle strategies. Overall, these findings suggest that some regional characteristics may act as CE drivers (i.e., *RD_private* and *RD_public*), whilst others may act as CE barriers (i.e., *Employment_KIS* and *ProcessInnovation_RIS*).

The results confirm the nuanced effects of various regional and organisational characteristics on distinct CE strategies. For instance, the *North-South* divide demonstrates a significant positive influence, highlighting regional disparities in adopting CE practices. In terms of organisational factors, the negative impact of *Employment_KIS* on CE strategies emphasises potential structural constraints tied to knowledge-intensive employment. In this sense, a potential explanation lies in the assumption that CE activities (particularly in the early stages of adoption) are more material- and logistics-intensive than knowledge-intensive. This result aligns with the findings of Buyukyazici and Quatraro (2025), who show that core CE activities (waste collection, recycling, repair, reuse, and maintenance) rely primarily on physical and psychomotor skills rather than advanced technical knowledge. This may explain why regions with higher shares of knowledge-intensive employment are less engaged in circular strategies such as recycling and reuse. Interestingly, *Digital Skills* is no significant for Redesign CE, suggesting its role as a targeted enabler rather than a universal driver. From a technological perspective, public and private R&D (*RD_private* and *RD_public*) efforts stand out as a consistent positive determinant, underlining the critical role of innovation investments by public and private entities (De Jesus *et al*., 2019; Fromhold-Eisebith, 2024). Conversely, *Process Innovation* consistently acts as a barrier across all CE strategies, potentially reflecting inefficiencies and/or mismatches in the way these innovations align with CE objectives, as well as the existence of technological optimization within existing linear production structures, rather than structural shifts towards circularity (Fromhold-Eisebith, 2024). These results are in line with Hartley *et al*. (2022) and Sopjani *et al*. (2020) who argue that process improvements often reinforce existing linear systems, leading to a state of 'linear lock-in' that hinders systemic transition towards CE model. Lastly, cooperation in innovation activities (*Cooperation*) has a positive, albeit varying, impact, further underscoring the importance of collaborative efforts in driving CE advancements (Brown *et al*., 2021).

In addition to the results of Table 3, Figure 1 illustrates the existence of relevant regional heterogeneities that should also be considered. In this respect, the GWR estimation manages this regional heterogeneity by obtaining spatially varying coefficients having as many β as spatial units (i.e., regions), which allows us to identify local patterns which are hidden when using global models such as OLS. The main difference between OLS and GWR is that the underlying assumption of OLS regression is that there is a stationary relationship between dependent and independent variables (i.e., this relationship is constant across the whole area), whilst the GWR tests whether this stationarity exists, accepting that it is possible that there is some variability across different regions (i.e., the effect of an independent variable on the dependent variable changes from one location to another). This is why GWR results offer a more detailed and appropriate approach to analysing CE's determinants, as they account for regional heterogeneity.

[INSERT TABLE 4 ABOUT HERE]

In this regard, Table 4 shows aggregate output for the GWR for the overall CE actions and the three specific ones. GWR results confirm previous baseline results and shed additional light on CE determinants. Specifically, for most of the covariates (i.e., 6 out of 11 for CE, 8 out of 11 for Reduce, 6 out of 11 for Recycle and 6 out of 11 for Redesign), there is non-stationarity, which implies that the effect of the covariates for which this test is confirmed differs across regions (i.e., the role played by these covariates is not the same for all regions).

Specifically, even though the impact of *DigitalSkills* remains modest, it emphasises the importance of digital skills in specific regional contexts. Similarly, *Employment_KIS* also shows non-stationarity, particularly for reduction and redesign strategies, suggesting that the structural employment composition significantly shapes regional CE outcomes. From an environmental perspective, *Heating_Days* demonstrates a consistent, though small, non-stationary effect across strategies. This points to climatic and environmental factors playing varying roles in shaping CE actions regionally. In the technological domain*, RD_private* emerges as a critical driver with significant and non-stationary (mainly) positive effects across all strategies, reinforcing the pivotal role of private sector innovation investments in advancing CE practices. Conversely, *ProcessInnovation* continues to act as a barrier, albeit with regional variation, underscoring its misalignment with CE strategies in certain contexts. The *Urban* variable shows localised influence, its effect being stronger in urbanised regions, particularly for reduction and recycling strategies.

[INSERT FIGURES 2, 3, 4 AND 5 ABOUT HERE]

Figures 2 to 5 illustrate the spatial variation of key drivers and barriers for CE strategies, revealing important regional differences across circular strategies. *RD_private*, a primary driver, demonstrates a consistently strong positive influence across regions, particularly for LQ_Reduce and LQ_Recycle, with the strongest effects observed in innovation-intensive regions. In contrast, its influence is weaker or even negligible in less industrialised or rural areas for LQ_Redesign, reflecting disparities in private-sector innovation investments.

DigitalSkills also emerges as a significant driver, but its impact varies more distinctly across CE strategies. For LQ_Reduce, digital skills show a broader positive impact, emphasising their importance in efficiency-driven strategies, whereas for LQ_Recycle, their influence is more localised, highlighting region-specific adoption of digital capabilities.

Conversely, barriers like *ProcessInnovation* and *Employment_KIS* display significant spatial heterogeneity, both showing stronger negative effects in industrial regions for LQ_Recycle and LQ_Redesign, potentially due to structural mismatches between existing innovations and CE objectives. Interestingly, *ProcessInnovation* exerts a relatively muted effect on LQ_CE overall, suggesting that this barrier may be more strategy-specific rather than universally detrimental.

Overall, these maps emphasise the need for regionally tailored approaches to leverage drivers like *RD_private* and *DigitalSkills*, while mitigating barriers such as process innovation inefficiencies and employment structural misalignments. They also underscore how certain strategies, such as LQ_Reduce, benefit from widespread enablers, whereas others, like LQ_Redesign, are more susceptible to localised constraints.

All in all, our empirical findings highlight the need to differentiate between various CE actions, as the effect of drivers and barriers vary across them. Furthermore, recent shifts in CE priorities reveal that firms and public institutions have traditionally focused on recycling activities, often overlooking other CE strategies (e.g., such as input reduction) which may have a significant impact and are currently experiencing faster growth.

5. Concluding remarks

This paper contributes to understanding the dynamics behind the implementation of CE actions taken by SMEs at the regional level within the EU, focusing on the drivers and barriers that influence this process, as well as the specific characteristics of CE actions. Whilst most previous studies primarily focus on recycling, our findings highlight the importance of adopting a holistic approach to CE analysis. This is why, in addition to an overall approach to CE, three specific CE strategies have been analysed (i.e., Reduce, Recycle and Redesign), to capture the heterogeneity in their underlying determinants. Our findings reveal that the factors shaping each strategy are not uniform, pointing to the need for more nuanced analytical and policy approaches. Additionally, our econometric approach helps to control for regional heterogeneity and identification of specific regional patterns in view of non-stationarity for most of the covariates, underscoring the need for tailored regional policies.

We have also shown the existence regional heterogeneity and spatial patterns, revealing important asymmetries in CE performance between leading and lagging regions. Regarding the drivers of CE actions, there are positive impacts of private R&D expenditure and digital skills on CE strategies, notably on recycling and reducing activities, whilst concerning barriers, some regional characteristics, like urbanisation and geographical location (North-South divide), may also play a relevant role.

Our results have direct implications for EU cohesion and circular transition policy agendas, as they shed some light on regional heterogeneity that may boost or restrict the implementation of CE measures, providing a solid scenario for the design of policy measures favouring this process. In this respect, our results suggest the need for i) tailored regional policies that consider regional strengths and barriers, ii) additional funds for private R&D and improved mechanisms to foster interfirm collaboration, iii) programmes aimed at improving digital skills, and iv) extended engagement and collaboration among governments, academic institutions, and business. In any case, in view of spatial heterogeneities and specificities of CE actions we strongly advise against general policy solutions to be applied elsewhere.

When discussing determinants of CE actions' implementation, we have considered different dimensions, i.e., those related to technology and those related to social and institutional issues. Although technology is an essential for certain technologically oriented CE actions, other do not involve a technological dimension and instead rely on social or institutional factors. This is why, to fully understand what is behind decisions to go circular, we must also consider social preferences and the institutional framework in the regions where firms are located. In this regard, it is important to take into consideration that, although CE measures are solely decided upon by firms, they must be accompanied by a stimulating policy environment (Mhatre *et al.*, 2021) with place-based policies involving multiple stakeholders (Segarra-Blasco *et al.*, 2024), from governments, universities and public research centres to business organisations and firms. Specifically, implementation of CE measures requires new technical and organisational knowledge that demands continuous R&D efforts and interindustry collaboration (Mhatre *et al*., 2021).

Although top-down actions are essential for advancing strategic EU objectives, they alone are not sufficient. Achieving a more effective implementation of these initiatives requires an equally strong bottom-up approach. Therefore, efforts should prioritise embedding CE principles within regional contexts to ensure a more impactful and locally adapted deployment. Nevertheless, as we cannot ignore the national institutional framework of EU regions, it is also important to encourage national governments to develop strategic plans for implementing CE actions, to identify specific targets, to monitor them and even to include some fines if the designed targets are not met, to better ensure that EU firms go circular.

Despite its contributions, this paper suffers from some limitations. Firstly, our results do not fully capture the actual performance of CE practices at regional level, as the indicators are limited to a restricted sample of SMEs answering the Eurobarometer Survey, which means that many actors are not considered and that the full picture of current circularity measures requires additional datasets. Secondly, we carry out an aggregate measure of CE actions, which is built upon more specific actions that do not necessarily capture the type of activities carried out by firms, which could go beyond our identification of CE actions. Thirdly, the dataset covers a single year (2021), which imposes some caution when trying to generalise our results for longer periods and limits potential control to address potential endogeneity in regressors. Fourthly, location quotients may exhibit a size bias when applied to regions of different sizes or to regions with a small number of firms responding to the survey.

Future research should overcome previous limitations in terms of measuring CE actions and the time span of the analysis and focus on specific industries, given that the industry dimension is of great importance in accordance with the heterogeneity of activities, production processes, energy consumption, raw materials, and waste generation at an industry level. Nevertheless, this highlights the fact that there is room for contributions about CE determinants.

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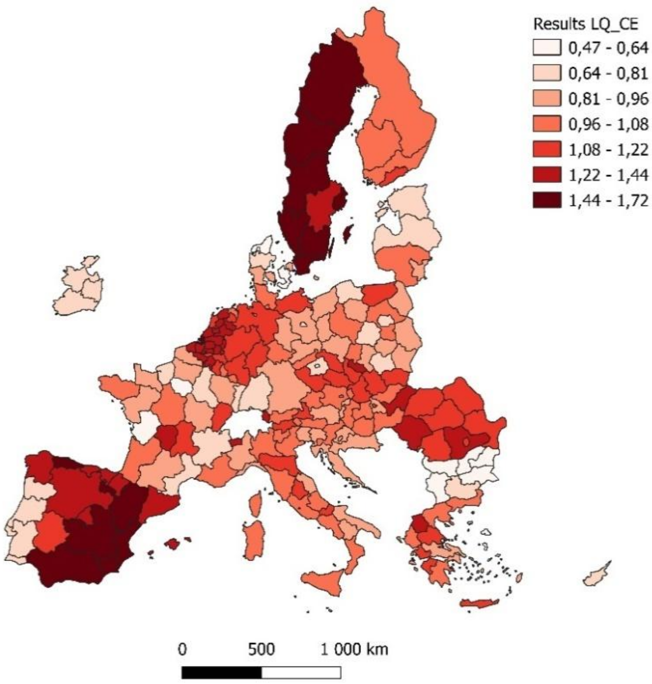
Figures

Figure 1. Spatial distribution of dependent variable (CE strategies)

LQ CE



LQ Reduce

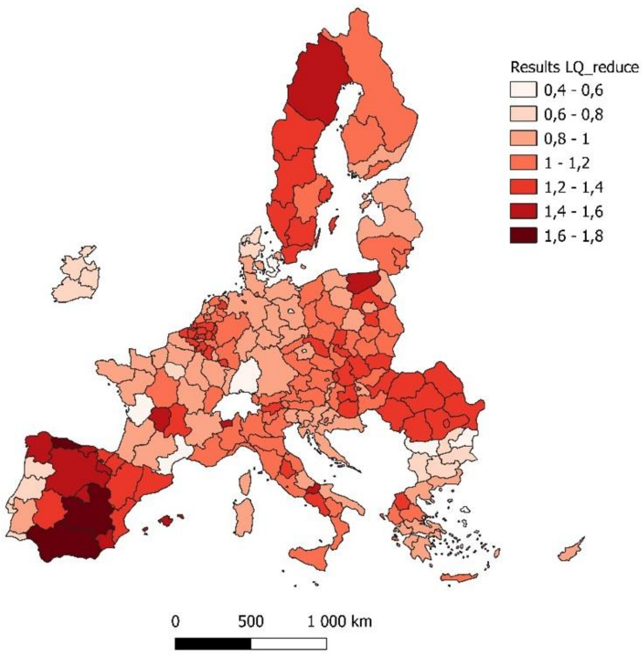
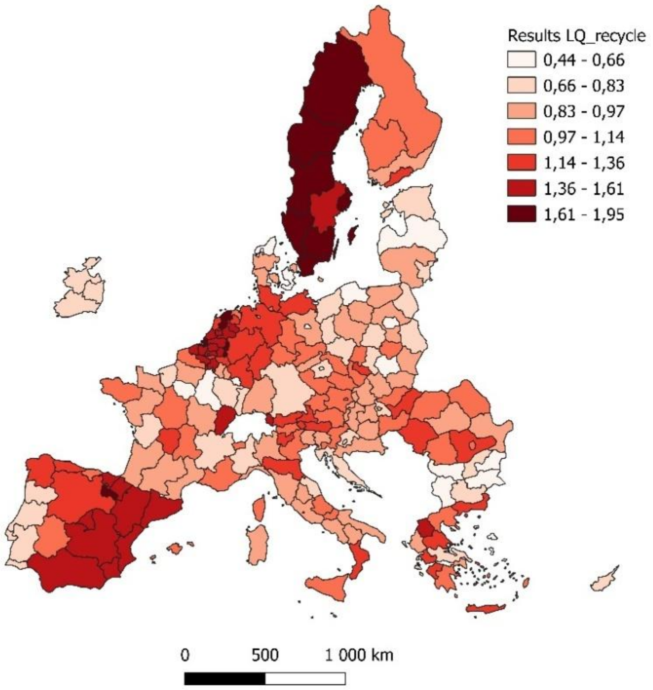
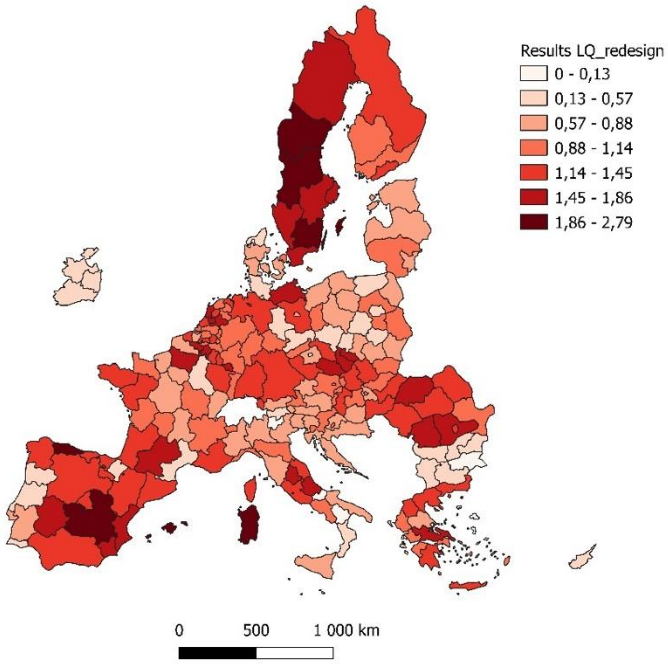


Figure 1. Spatial distribution of dependent variable (CE strategies) (cont.)

LQ_Recycle



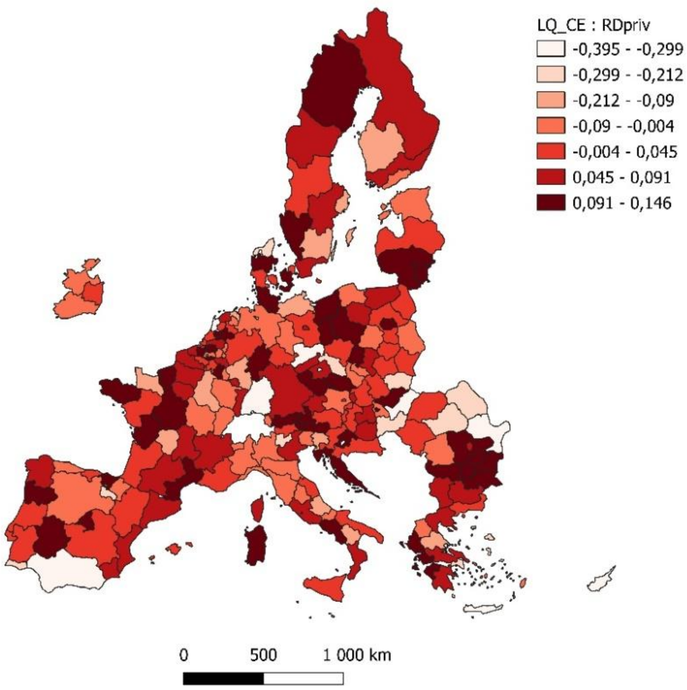
LQ_Redesign



Source: compiled by authors.
Note: Values reflect a composite Location Quotient (LQ) index measuring regional specialisation in CE actions relative to the EU-27 average. The map shows LQ values for each one of the three CE strategies—LQ_Reduce, LQ_Recycle, and LQ_Redesign—or for the overall CE index (LQ_CE), as indicated in the legend title. An LQ_* > 1 denotes above-average regional CE engagement.

Figure 2. GWR approach. Focus on a particular CE strategies' driver:
RD_private

LQ_CE



LQ_Reduce

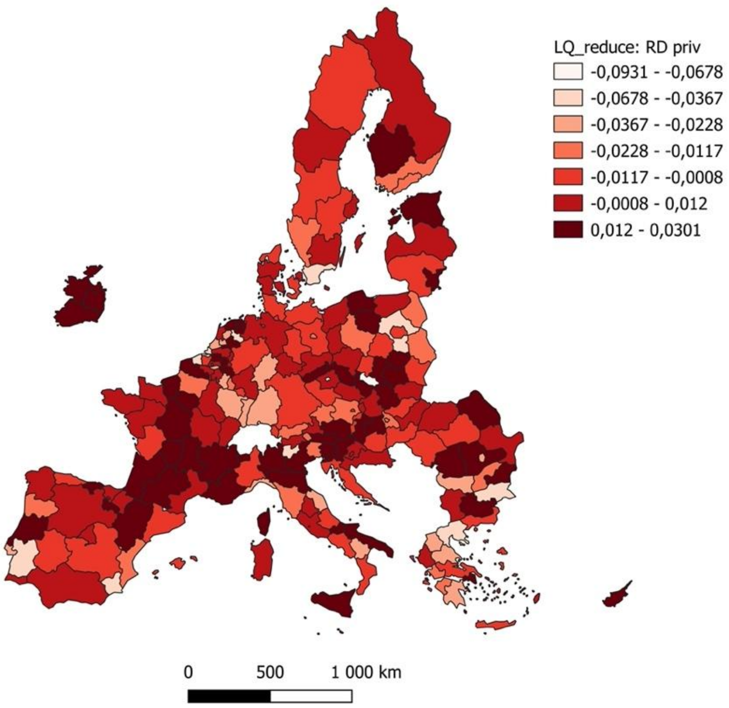
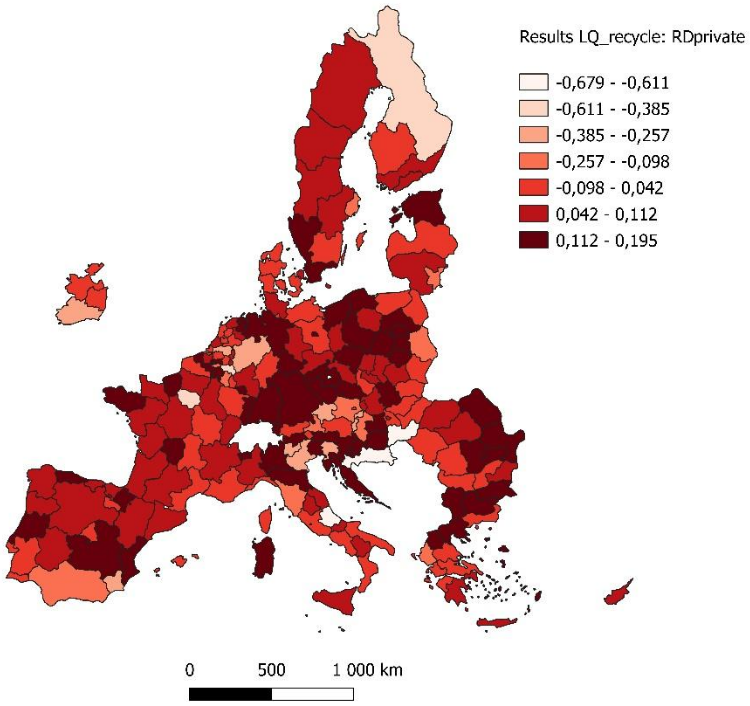
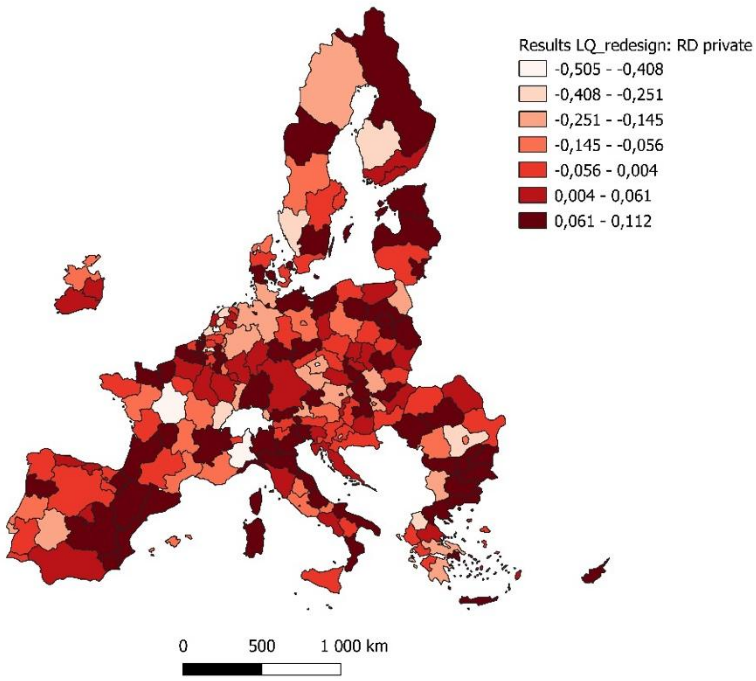


Figure 2. GWR approach. Focus on a particular CE strategies' driver:
***RD_private* (cont.)**

LQ_Recycle



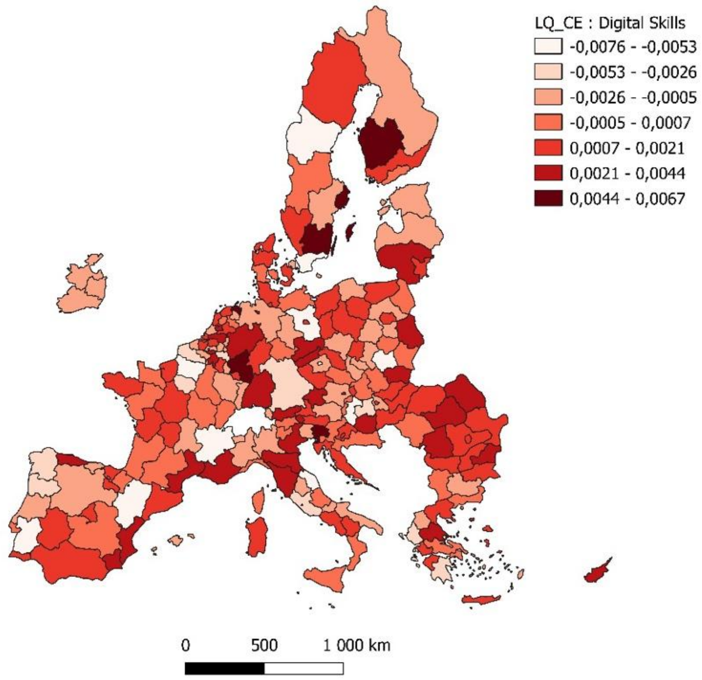
LQ_Redesign



Source: compiled by authors.
Note: This map displays the regional coefficients from a GWR regression estimating the impact of business R&D expenditure as % of GDP (RD_private) on regional specialisation in CE (LQ_CE). Higher values in the legend indicate stronger positive influence, especially relevant for LQ_Reduce and LQ_Recycle.

Figure 3. GWR approach. Focus on a particular CE strategies' driver: *Digitalskills*

LQ_CE



LQ_reduce

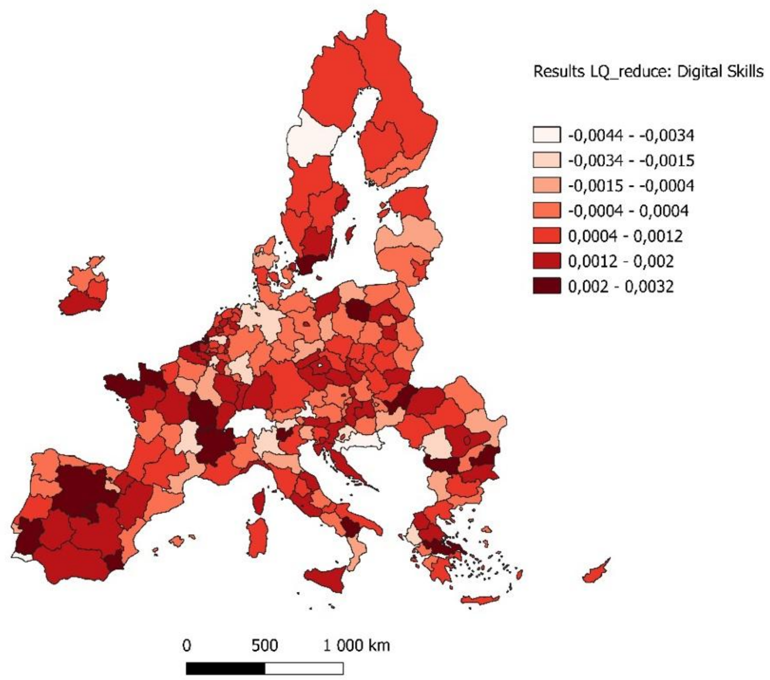
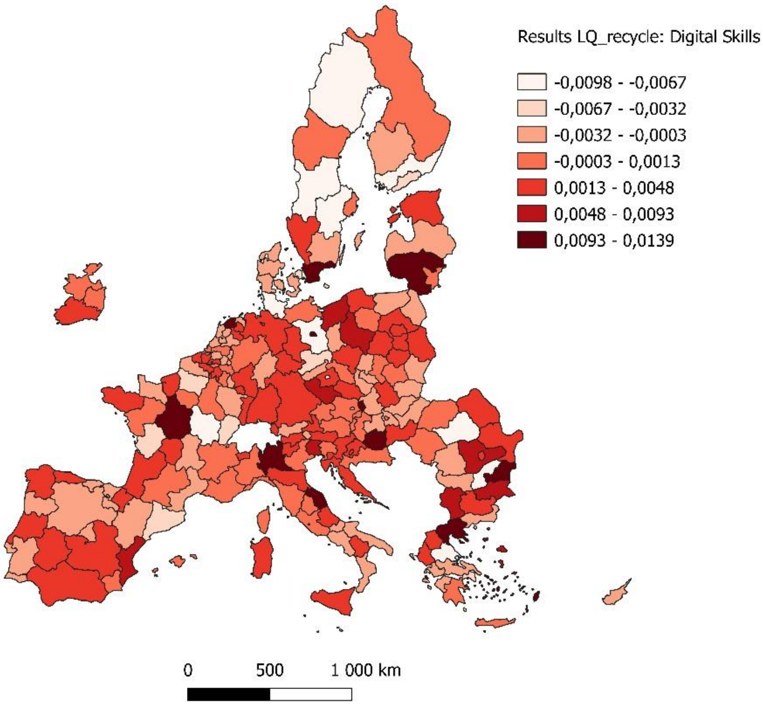
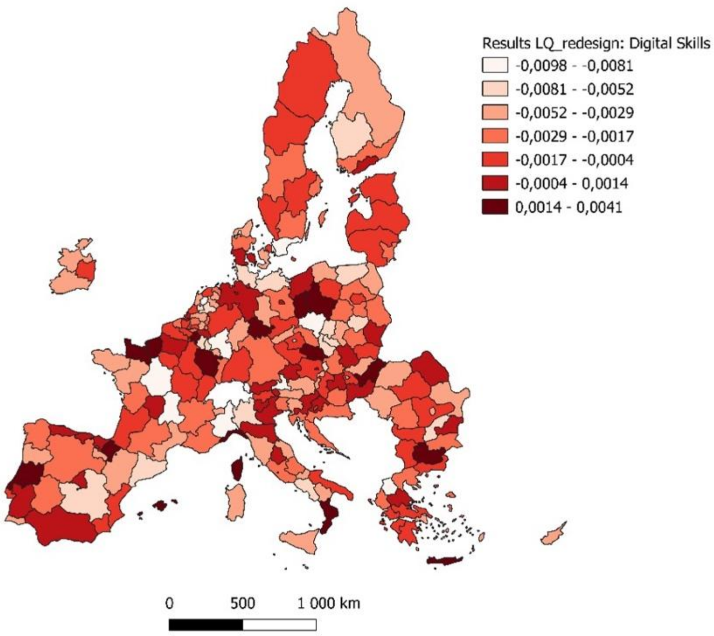


Figure 3. GWR approach. Focus on a particular CE strategies' driver: *Digitalskills (cont.)*

LQ_Recycle



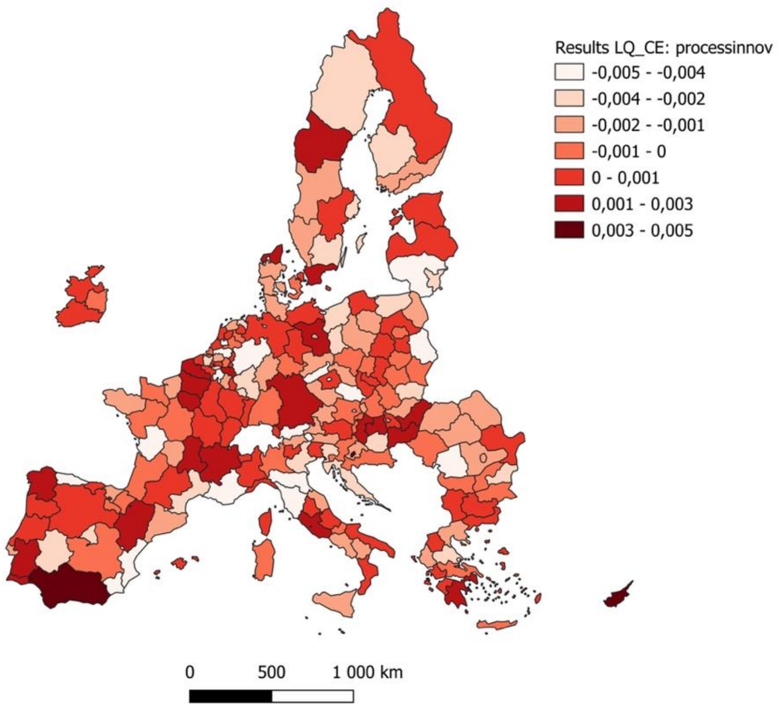
LQ_Redesign



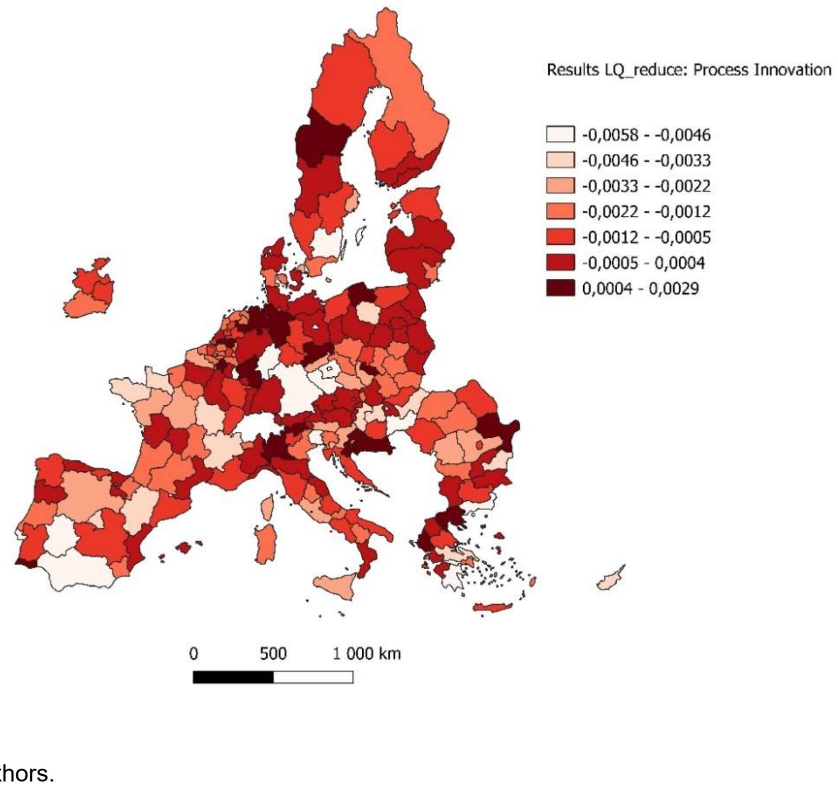
Source: compiled by authors.
Note: This map displays the regional coefficients from a GWR regression estimating the impact of Digital Skills on regional specialisation in CE (LQ_CE). Higher values in the legend indicate stronger positive influence, but its impact varies more distinctly across CE strategies.

Figure 4. GWR approach. Focus on a particular CE strategies' barrier:
Processinno

LQ_CE



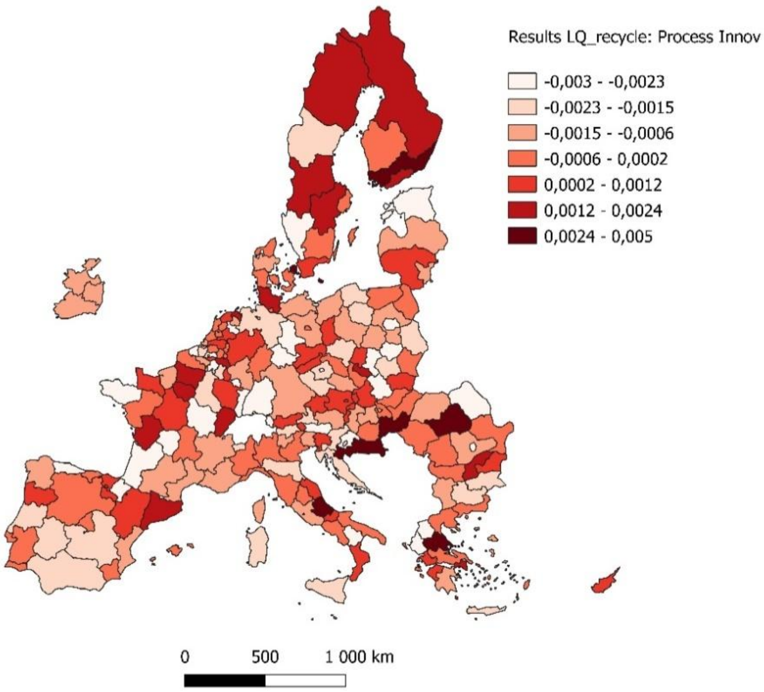
LQ_Reduce



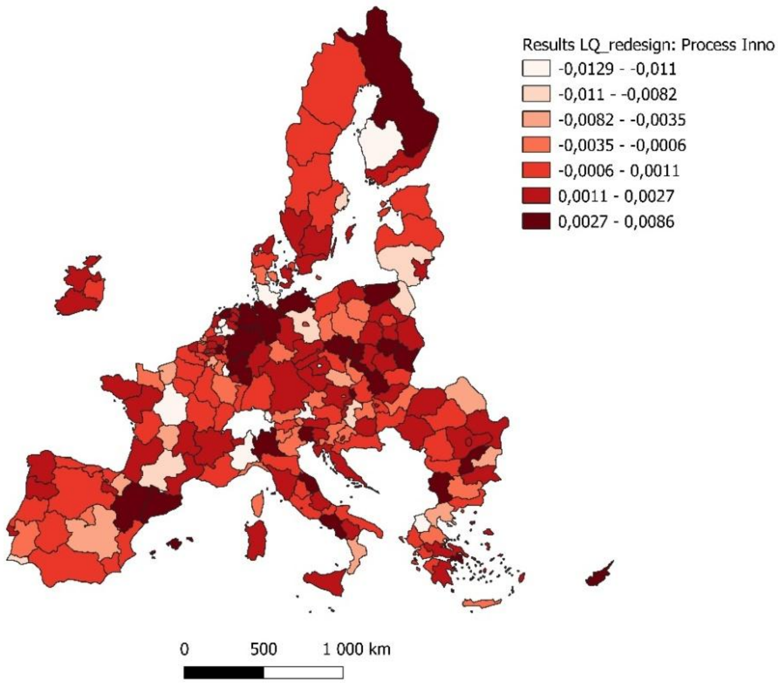
Source: compiled by authors.

Figure 4. GWR approach. Focus on a particular CE strategies' barrier: *Processinno (cont.)*

LQ_Recycle



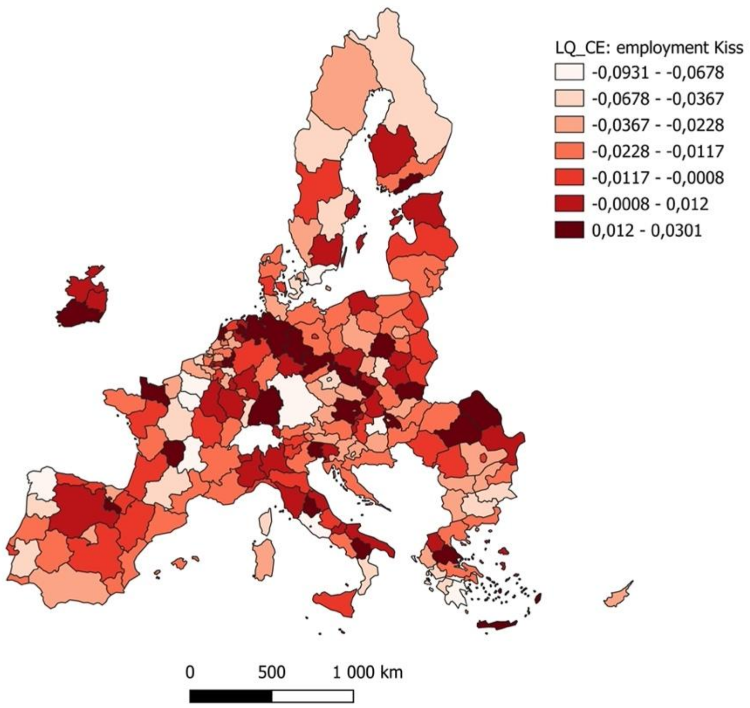
LQ_Redesign



Source: compiled by authors.
Note: This map displays the regional coefficients from a GWR regression estimating the impact of the share of innovative SMEs (*ProcessInnovation*) on regional specialisation in CE. The results display significant spatial heterogeneity, both showing stronger negative effects in industrial regions for LQ_Recycle and LQ_Redesign.

Figure 5. GWR approach. Focus on a particular CE strategies' barrier: *Employment_KIS*

LQ_CE



LQ_Reduce

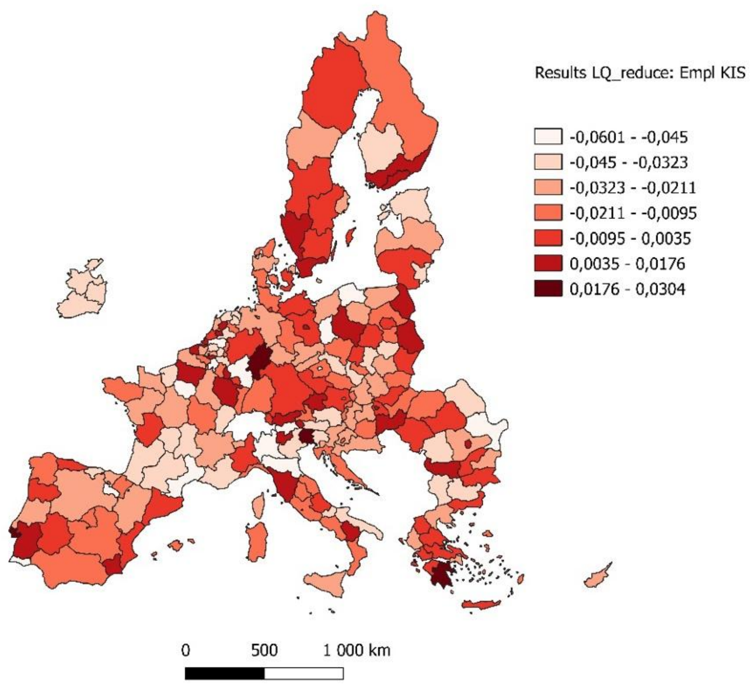
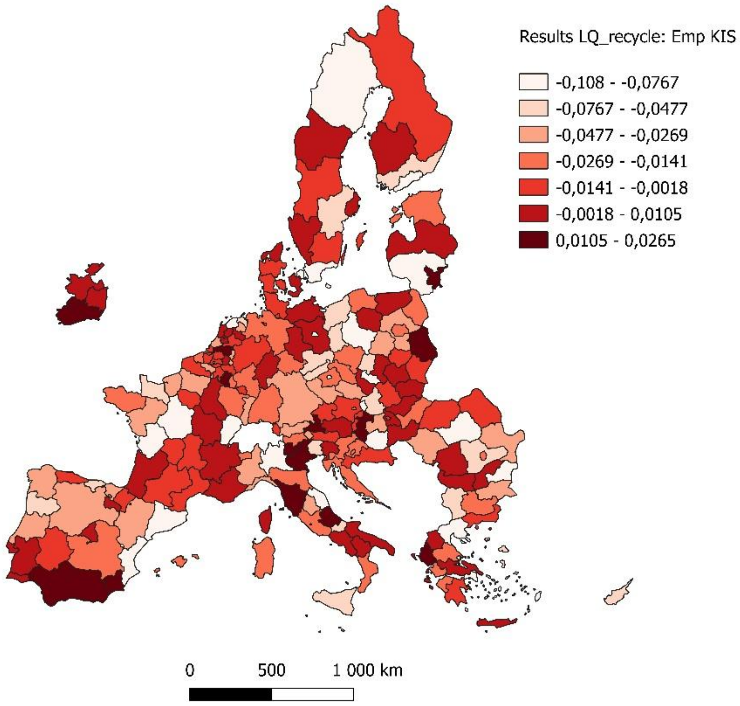
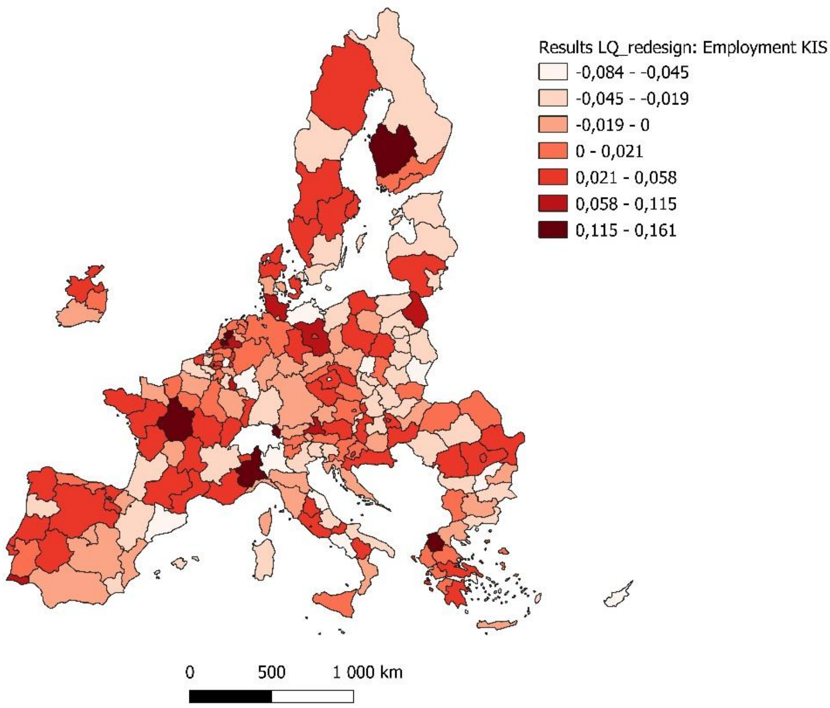


Figure 5. GWR approach. Focus on a particular CE strategies' barrier: *Employment_KIS (cont.)*

LQ_Recycle



LQ_Redesign



Source: compiled by authors.

Note: This map displays the regional coefficients from a GWR regression estimating the impact of the share employment in KIS (*EmploymentKIS*) on regional specialisation in CE. The results display significant spatial heterogeneity, both showing stronger negative effects in industrial regions for LQ_Recycle and LQ_Redesign.

Tables

Table 1. Flash Eurobarometer Survey 498 CE actions

Water reduction	Reduce
Energy reduction	
Waste reduction	
Material reduction	
Switch to suppliers of greener materials	Recycle
Predominant use of renewable energy	
Sale of scrap to other firms	
Recycle	
Design products	Redesign

Source: compiled by authors.

Table 2. Descriptive statistics of explanatory variables

Variable	Definition	Source	Mean	Std. Dev.	Min	Max
Dependent variables (CE strategies)						
LQ_CE	Location Quotient in CE actions	Authors on Flash Eurobarometer Survey 498	1.05	0.25	0.47	1.72
LQ_Reduce	Location Quotient in CE Reduce actions	Authors on Flash Eurobarometer Survey 498	1.05	0.25	0.37	1.80
LQ_Recycle	Location Quotient in CE Recycle actions	Authors on Flash Eurobarometer Survey 498	1.06	0.31	0.44	1.95
LQ_Redesign	Location Quotient in CE Redesign actions	Authors on Flash Eurobarometer Survey 498	1.05	0.45	0.00	2.79
Independent variables						
Institutional						
GovernmentQuality	Index capturing average citizen's perceptions and experience with corruption, quality and impartiality of three essential public services – health, education, and policing – in their region of residence.	European Quality of Governance EQI Data	0.03	0.99	-2.15	1.71
NorthSouth	A dummy variable that takes the value of 1 if the region belongs to Portugal, Spain, Italy, Greece, Croatia, Bulgaria, or Romania, and 0 otherwise.	Authors	0.35	0.48	0.00	1.00
Socioeconomic and organisational						
Employment_KIS	Employment in knowledge-intensive activities (% of total employment).	Eurostat	3.59	2.16	0.00	11.20
Digitalskills	Individuals with above basic overall digital skills. "Digital skills" refer to the advanced competencies that individuals possess to perform activities on the internet in four specific areas (information, communication, problem-solving, content creation).	RIS	103.60	48.85	3.52	212.71
Learning	Population involved in lifelong learning	RIS	103.29	73.74	0.00	269.39
Urban	A dummy variable that takes the value of 1 if the region is considered as urban, and 0 otherwise	Authors on De Beer, J, Van der Gaag, N. and Van der Erf, R. (2014)	0.28	0.45	0.00	1.00
Environmental						
Heating days	Number of heating degree days.	Eurostat	2470.22	879.23	515.23	6421.79
Technological and Supply Chain						
RD_public	R&D expenditure in the public sector (% of GDP).	Eurostat	0.15	0.20	0.00	1.24
RD_private	R&D expenditure in the business sector (% of GDP).	Eurostat	0.81	0.88	0.00	4.80
ProcessInnovation	SMEs introducing business process innovations (innovators) (% of SMEs).	RIS	107.23	54.18	0.00	222.75
Cooperation	Innovative SMEs collaborating with others (% of SMEs).	Regional innovation scoreboard (RIS)	114.28	68.99	6.68	286.79

Source: compiled by authors from The Flash Eurobarometer Survey 498.

Table 3. Determinants of CE strategies (OLS approach)

Variables	*LQ_CE*	*LQ_Reduce*	*LQ_Recycle*	*LQ_Redesign*
				Institutional
GovernmentQuality	-0.0002	-0.0011**	0.0006	0.0006
	(0.000)	(0.000)	(0.000)	(0.001)
NorthSouth	0.1168***	0.1310***	0.1094**	0.0895
	(0.044)	(0.046)	(0.050)	(0.089)
				Socioeconomic and Organisational
Employment_KIS	-0.0317***	-0.0287***	-0.0400***	-0.0106
	(0.009)	(0.009)	(0.011)	(0.016)
DigitalSkills	0.0021***	0.0025***	0.0019***	0.0017
	(0.001)	(0.001)	(0.001)	(0.001)
Learning	0.0005	-0.0001	0.0011**	0.0010
	(0.000)	(0.000)	(0.000)	(0.001)
Urban	0.0525	0.0689*	0.0532	-0.0165
	(0.037)	(0.035)	(0.046)	(0.076)
				Environmental
Heating_Days	0.0000	0.0000*	-0.0000	-0.0000
	(0.000)	(0.000)	(0.000)	(0.000)
				Technological and Supply Chain
RD_public	0.1673**	0.2162***	0.1167	0.1738
	(0.077)	(0.078)	(0.133)	(0.174)
RD_private	0.0890***	0.0749***	0.1092***	0.0647*
	(0.020)	(0.016)	(0.027)	(0.037)
ProcessInnovation	-0.0020***	-0.0021***	-0.0019***	-0.0021**
	(0.000)	(0.000)	(0.000)	(0.001)
Cooperation	0.0007**	0.0003	0.0011***	0.0009
	(0.000)	(0.000)	(0.000)	(0.001)
Constant	0.8536***	0.9339***	0.7810***	0.8226***
	(0.099)	(0.093)	(0.115)	(0.173)
Observations	208	208	208	208
R-squared	0.300	0.275	0.355	0.075
AIC	-45.6788	-49.9268	27.5369	251.9622
VIF	2.34	2.34	2.34	2.34

Source: compiled by authors; robust standard errors between brackets; *** p<0.01, ** p<0.05, * p<0.1.

Table 4. Determinants of CE strategies (GWR approach)

	LQ_CE				LQ_ Reduce				LQ_ Recycle				LQ_ Redesign			
Variables	Min	Max	Median (p50)	Non-Stationarity Test	Min	Max	Median (p50)	Non-Stationarity Test	Min	Max	Median (p50)	Non-Stationarity Test	Min	Max	Median (p50)	Non-Stationarity Test
Institutional																
GovernmentQuality	-0.193	0.419	0.022		-0.165	0.039	-0.042		-0.139	0.598	0.094		-0.207	0.246	-0.013	
NorthSouth	-0.426	0.514	0.081		-0.174	0.330	0.072	***	-0.392	0.522	0.125		-0.537	0.379	-0.176	
Socioeconomic and Organisational																
Employment_KIS	-0.093	0.030	-0.013		-0.060	0.030	-0.017	***	-0.108	0.027	-0.013	*	-0.084	0.161	0.004	**
DigitalSkills	-0.008	0.007	0.001	***	-0.004	0.003	0.001	***	-0.010	0.014	0.001	***	-0.010	0.004	-0.002	*
Learning	-0.003	0.006	0.001	**	-0.001	0.003	0.000		-0.005	0.007	0.001	***	-0.006	0.008	0.001	*
Urban	-0.134	0.501	0.046	*	-0.029	0.392	0.059	*	-0.170	0.555	0.037		-0.194	0.722	0.021	
Environmental																
Heating_Days	-0.000	0.000	0.000	***	-0.000	0.000	0.000	**	-0.000	0.000	-0.000	**	-0.000	0.001	-0.000	***
Technological and Supply Chain																
RD_public	-0.888	0.687	-0.074		-0.484	0.363	-0.014	**	-0.428	0.812	-0.099		-2.209	0.776	-0.131	
RD_private	-0.395	0.146	0.033	***	-0.416	0.090	0.037	***	-0.679	0.195	0.066	***	-0.505	0.112	0.011	***
ProcessInnovation	-0.005	0.005	-0.001	***	-0.006	0.003	-0.001	***	-0.003	0.005	-0.000	**	-0.013	0.009	0.001	***
Cooperation	-0.003	0.002	0.001		-0.001	0.002	0.000		-0.003	0.002	0.001		-0.004	0.002	0.000	
Observations	208	208	208		208	208	208		208	208	208		208	208	208	
R-squared		0.304				0.250				0.365				0.075		
AIC		-11.673				3.131				19.471				98.523		

Source: compiled by authors; *** p<0.01, ** p<0.05, * p<0.1.

Appendices

Table A.1. Correlation of explanatory variables

Variables	*Employment_KIS*	*RD_public*	*RD_private*	*Cooperation*	*ProcessInnovation*	*Heating_Days*	*Learning*	*DigitalSkills*	*GovernmentQuality*	*NorthSouth*	*Urban*
Employment_KIS	1										
RD_public	0.2646*	1									
RD_private	0.4276*	0.2704*	1								
Cooperation	0.1489	0.1927*	0.2789*	1							
ProcessInnovation	0.0976	0.1996*	0.2096*	0.6709*	1						
Heating_Days	0.1974*	-0.0088	0.3108*	0.1986*	-0.1182	1					
Learning	0.2653*	-0.0637	0.1753	0.3078*	0.2721*	0.3512*	1				
DigitalSkills	0.1902*	-0.2029*	0.0315	0.3833*	0.3731*	0.1654	0.8158*	1			
GovernmentQuality	0.1756	0.1309	0.2508*	0.4444*	0.4132*	0.2678*	0.5632*	0.4654*	1		
NorthSouth	-0.3142*	0.0336	-0.2582*	-0.3153*	-0.0379	-0.5478*	-0.2570*	-0.2664*	-0.4064*	1	
Urban	0.4678*	0.2572*	0.1361	0.0967	0.1060	-0.0824	0.2275*	0.2170*	0.1140	-0.0978	1

Source: compiled by authors; * $p<0.05$.