ESTRATEGIAS TERRITORIALES Y PRODUCTIVAS EN UN CONTEXTO DE CAMBIO GLOBAL

TERRITORIAL AND PRODUCTIVE STRATEGIES IN A CONTEXT OF GLOBAL CHANGE

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GGE Grupo de Geografía Económica
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CAPÍTULO 22.

CRITICAL TRANSITIONS: UNPACKING DECARBONIZATION STRATEGIES IN PORTUGUESE INDUSTRY AND REGIONAL DISPARITIES

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Abstract:

In the wake of the Paris Agreement, the urgency for decarbonization has intensified globally, prompting varied responses from different regions and sectors. This study critically examines the uneven decarbonization trajectories of Portuguese firms within the framework of the Portugal 2020 (PT2020) program, informed by transition theory and regional innovation systems. Employing a multi-method approach that combines natural language processing and a systematic literature review, we identify and categorize the decarbonization strategies of 278 out of 2,793 firms funded by PT2020 between 2020 and 2023.

Our findings reveal a modest (less than 10 % of all projects) but pivotal engagement in decarbonization, predominantly focused on the Porto metropolitan area and adjacent regions, indicating a pattern of uneven geographical transitions. Larger, established firms predominantly undertake these initiatives, reflecting a skew in policy effectiveness towards more stable entities. The most common pathways—demand and co-benefits (49 %) and decarbonization of electricity (34 %)—suggest a preference for immediately actionable strategies (electrification of uses and technological breakthroughs).

This study underscores the disparity in decarbonization efforts across firms, but also regions, correlating higher industrial productivity and urbanization with increased activity. Such trends reveal the influence of existing economic structures and regional capacities on the adoption of green technologies, which exacerbate regional inequalities in the face of global decarbonization mandates.

This study improves the understanding on the potential of decarbonization to increase or decrease inequalities among companies and regions. It provides crucial lessons for policies aiming to accelerate decarbonization to achieve the 2030 goals. Further research is required to explore the impact of regional specialization on decarbonization strategies and to develop more inclusive and equitable policies.

Keywords:

Innovation, Decarbonization Policy, Firms strategies, Regions, Portugal

Resumen:

A raíz del Acuerdo de París, la urgencia por acometer la descarbonización se ha intensificado a nivel mundial, provocando respuestas variadas de diferentes regiones y sectores. Este estudio examina críticamente las desiguales trayectorias de descarbonización de las empresas portuguesas en el marco del programa Portugal 2020 (PT2020), basándose en la teoría de la transición y los sistemas regionales de innovación. Empleando un enfoque multimétodo que combina el procesamiento del lenguaje natural y una revisión sistemática de la literatura, identificamos y categorizamos las estrategias de descarbonización de 278 de las 2.793 empresas financiadas por PT2020 entre 2020 y 2023. Nuestros resultados revelan un compromiso modesto (menos del 10% de todos los proyectos), pero fundamental en la descarbonización, centrado predominantemente en el área metropolitana de Oporto y las regiones limítrofes, lo que indica un patrón geográfico desigual de transiciones. Las empresas más grandes y consolidadas son las que más se comprometen con estas iniciativas, lo que refleja un sesgo en la eficacia de las políticas hacia entidades más estables. Las acciones más más comunes -demanda y beneficios colaterales (49 %) y descarbonización de la electricidad (34 %)- sugieren una preferencia por las estrategias de acción inmediata (electrificación de los usos y avances tecnológicos). Este estudio subraya la disparidad de los esfuerzos de descarbonización entre empresas, pero también entre regiones, correlacionando la mayor productividad industrial y la urbanización con el aumento de la actividad descarbonizadora. Estas tendencias revelan, por tanto, la influencia de las estructuras económicas y las capacidades regionales previas en la adopción de tecnologías verdes, que agravan las desigualdades regionales frente a los mandatos mundiales de descarbonización. El estudio además mejora la comprensión sobre el potencial de la descarbonización para aumentar o disminuir las desigualdades entre empresas y regiones y proporciona lecciones cruciales para las políticas destinadas a acelerar la descarbonización y alcanzar los objetivos de 2030. Se requiere más investigación para explorar el impacto de la especialización regional en las estrategias de descarbonización y para desarrollar políticas más inclusivas y equitativas.

Palabras clave:

Innovación, políticas de descarbonización, estrategias empresariales, regiones, Portugal

Introduction

In the wake of the Paris Agreement, the global urgency for decarbonization has intensified, prompting countries, industries, and firms to adopt strategies aimed at mitigating climate change. Decarbonizing the economy is now at the forefront of the political agenda, both at the EU level like the European Green Deal and the global level such as the United Nations Framework Convention on Climate Change (UNFCCC). These efforts are part of a broader sustainability transition, challenging policymakers at national, regional, and municipal levels to balance economic growth with environmental sustainability.

The literature on decarbonization has expanded significantly in recent years, with scholars exploring the relationship between firms, regions, and sustainability transitions (Santoalha and Boschma, 2021; Markard and Rosenbloom, 2022). While these studies provide valuable insights into the role of regional specialization and proximity effects in driving innovation, there remains a gap in understanding the specific decarbonization pathways adopted by firms in different regional contexts. The novelty of the paper lies precisely in the analysis of individual decarbonization strategies of companies in conjunction with the regional context where they emerge.

This gap is particularly evident in studies focused on Portugal, where the effects of national climate policies like the PT2020 program on firms' decarbonization efforts have yet to be fully explored. Portugal has been an active participant in these global decarbonization efforts, with

the PT2020 program providing a framework for innovation and sustainability transitions within its national and regional economic structures. This paper aims to unpack the decarbonization strategies of Portuguese firms, analysing the uneven geographical and industrial distribution of these efforts. By focusing on firms that received funding from PT2020, this paper explores how regional disparities, and existing economic structures influence the adoption of green technologies.

This paper contributes to the growing body of literature on sustainability transitions, with a focus on decarbonization strategies at the firm level and the regional factors that drive or hinder these efforts. Through a multi-method approach combining natural language processing and systematic literature review, this research identifies the decarbonization strategies of 278 firms funded by PT2020 and explores the policy implications of these findings for regional development and innovation systems. Firms and regions show different dynamics of decarbonization initiatives. Decarbonization pathways are varied, reflecting the distinct characteristics of firms and their regional contexts. This study contributes to the understanding of broader implications of these disparities in shaping the adoption of sustainable practices.

The structure of this paper is organized as follows. The next section examines the extant literature on regional transitions to sustainability, particularly focusing the contextual factors influencing decarbonization. Following that, the Research Methodology section depicts the multi-method approach employed, including the use of natural language processing and firm-level data analysis. The Results section presents key findings. In the Discussion section, the paper explores the impact of contextual factors, such as industrial productivity and CO_2 emissions. Finally, the paper concludes with recommendations for future research and outlines policy implications of the findings aimed at promoting sustainability transitions in different industrial and regional contexts.

Theoretical foundations and regional dynamics of decarbonization

Decarbonization, sustainability transitions and space

Decarbonising the economy is an essential part of sustainability transition strategies, which challenge policymakers at national, regional and municipal levels (Gibbs and O'Neill, 2017; United Nations, 2017), although its implementation can have very different impacts on inequalities and sustainable development (Bina, 2013; IPCC, 2023).

The concept of decarbonization is grounded in broader theories of sustainability transitions, which emphasize the shift from fossil-fuel-dependent economies to greener, low-carbon alternatives. Transition theory, which includes constructs like the multi-level perspective (MLP) and technological innovation systems (TIS), provides a framework for understanding how such shifts occur at the intersection of technological innovation, policy, and societal change. These theories emphasize the crucial role of firms as agents of change, adopting decarbonization strategies influenced by both market dynamics and policy interventions (Geels, 2002, 2024). However, the transitions analysis often overlooked the dynamics occurring at various spatial scales, whereas the economic geography overlooked the role of agency and constraints to diversification such as socio-technical regimes (Boschma et al., 2018). This is particularly limiting when dealing with the role of social and spatial disparities in the transition to net-zero.

Regional disparities and decarbonization

Recent literature has begun to address the spatial disparities that shape the capacity for regions to engage in decarbonization like net-zero transitions (Binz et al., 2020). Disparities underscore the importance of tailoring policy interventions to local contexts, ensuring that decarbonization efforts do not exacerbate regional inequalities. In fact, many non-core regions often exhibit weak economic structures and limited innovation dynamics, which create obstacles for the development of new environmentally pathways (Grillitsch and Hansen, 2019).

Decarbonization efforts are driven by factors like regional specialization (Trippl et al., 2020), firm characteristics (Neffke et al., 2018), and policy intervention (Santoalha and Boschma, 2021). Sustainability transitions exhibit a distinct geographical dimension because they are influenced by the specific conditions of regions, such as the availability of natural resources, the concentration and sectoral composition of industries, regional innovation capacities, and the presence of supportive institutional frameworks. These factors shape how decarbonization efforts unfold across different regions, leading to variations in the pace and nature of transitions, as well as in the ability of regions to adapt to and benefit from sustainable practices.

Regional innovation systems (RIS) explain the differences between regions in terms of their ability to diversify and pursue new strategies, such as decarbonization strategies. Core regions with strong RISs, such as metropolitan areas, tend to lead in adopting new green technologies, while regions dominated by less advanced industrial structures show more difficulties in processes of transitioning towards greener practices (Vale et al., 2024a). Peripheral regions, in particular, struggle due to institutional thinness and lack of technological capabilities (Grillitsch and Hansen, 2019). They additionally face important socio-political challenges as economic inequalities and power asymmetries hinder equitable decarbonization efforts, as the notion of just transitions highlights (Lawhon and Murphy, 2012; Swilling, 2020).

Peripheral challenges in decarbonization

Peripheral regions are not simply defined by geographic isolation but also by their position in global networks, which limits their access to the resources necessary for sustainability transitions. As Binz et al. (2016) and Coenen et al. (2021) argue, a multi-scalar approach is indispensable for understanding and implementing sustainability transition initiatives. In the same vein, Vale et al. (2024a) advocate peripheral regions must navigate not only local challenges but also global market and policy pressures.

Peripheral regions are significantly disadvantaged in sustainability transitions due to their structural, economic, and institutional limitations. These regions often face socio-spatial unevenness, asset fragility, and network positionality, which constrain their ability to diversify into green technologies and adopt sustainable practices (Grillitsch and Hansen, 2019). Unlike core regions, which benefit from robust industrial bases and innovation ecosystems, peripheral regions are often locked into polluting industries and lack the resources to diversify toward decarbonization.

Existing research also highlights the challenges faced by firms in regions dominated by less advanced industrial structures, where innovation dynamics are weaker. The multi-scalar approach proposed by Binz et al. (2016) and Coenen et al. (2021) is essential for understanding how regional, national, and global factors intersect to shape decarbonization efforts. Additionally, the literature emphasizes the importance of path dependency and lock-ins in peripheral regions, where established industries and incumbent actors resist changes that could disrupt their economic foundations. For example, Tödtling and Trippl (2018) highlight how traditional industries in these regions often act as barriers to green innovation, creating significant challenges for policy interventions aimed at fostering sustainability transitions.

At the same time, however, there is a growing body of research suggesting that peripheral regions are not necessarily doomed to failure in sustainability transitions. Relational approaches to economic geography emphasize that peripheral regions can overcome their structural disadvantages by forging new connections and integrating into global innovation systems (Binz et al., 2016). Vale et al. (2024a) also discuss how peripheral regions might leverage their positionality within multi-scalar networks to anchor external resources and support green path development.

Decarbonization is increasingly important in firms' investment strategies as they face raising pressures from the market and regulation (Bento et al., 2021). Market allocation alone may not suffice to deliver the required level of investment in a timely manner, given prevalent market failures and difficulties in benefit appropriation. So, public policies, like PT2020 (EU funded),

may provide essential support to enterprises. In this paper, we explore to what extent firm's investment in decarbonisation strategies is related with regional industrial productivity (proxy for capital intensity) and with CO_2 industry emissions. We also intend to understand the effect of regional specialisation and internationalisation of industrial sectors on firm's investment in decarbonisation strategies.

In summary, while peripheral regions face significant challenges in adopting decarbonization strategies, the literature underscores the need for place-sensitive policies that address regional disparities in innovation capacity, industrial structure, and socio-political dynamics. By analysing firm-level strategies within the PT2020 framework, this study advances previous research (Vale et al., 2024b) and contributes to the understanding of how regional innovation systems and industrial specialization shape sustainable practices, offering insights on navigating the «troubled waters» of sustainability transitions (Vale et al., 2024a).

Research methodology

This study employs a multi-method approach to investigate the decarbonization strategies of Portuguese firms within the framework of the PT2020 program. This paper adopts a typology of decarbonization pathways developed in the SUS2TRANS research project, which utilized Natural Language Processing techniques to conduct a systematic analysis of one million research papers pertaining to decarbonization studies and published from 2011 to 2021 (Alves et al., 2023). Table 1 depicts the 6 main types/pathways of decarbonization.

The primary data for this research comes from the Portuguese agency for competition and innovation IAPMEI and consists of decarbonization project reports submitted by firms that received funding from the PT2020 program under the incentive systems by region. These reports provide detailed descriptions of the strategies and technologies firms are adopting to meet decarbonization targets. Additionally, firm characteristics such as size, location, and industrial sector were collected from multiple sources (firm's websites, business portals, etc.) to enable a deeper analysis of regional disparities (Table 2). In addition, CO_2 emissions and population distribution indicators at the NUTS3 level are considered to analyse contextual factors.

Table 1. Description of decarbonization pathways

Theme	Description
Technological Breakthrough	This approach focuses on the development and implementation of cutting-edge technological innovations to enable deep decarbonization and create highly efficient and sustainable energy systems.
Electrification of Uses	This approach involves the electrification of various end-uses with the replacement of fossil fuel-based energy sources. It includes charging infrastructures for electric vehicles and smart electric grids.
Integrated Policy	This integrative approach involves harmonization of policy frameworks, including regulation, carbon taxes and market-driven incentives for sustainability transitions.
Decarbonization of Electricity	This strategy focuses on the decarbonization of the electricity sector, through an increasing use of renewable energy sources and the reduction of fossil fuel-based generation.
Demand Reduction	This pathway targets energy conservation and co-benefits like air quality and cost savings, derived from lower energy demand and efficient energy use (e.g. urban mobility).
Land Use and Circularity	This combined pathway considers the role of land use in reducing emissions and prioritizes resource efficiency through circular economy principles.

Source: SUS2TRANS

Table 2. Data sources

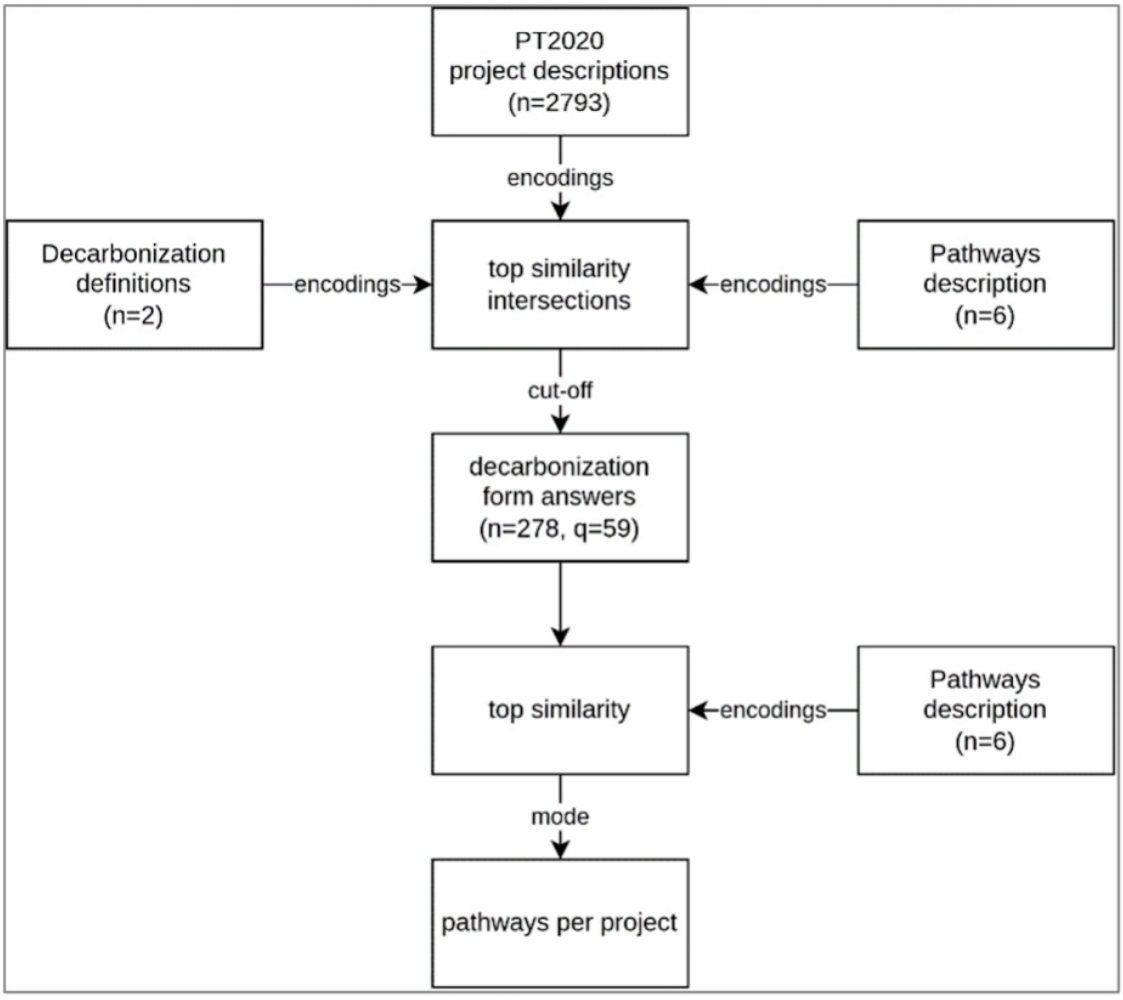
Data (year)	Description	Sources
PT2020 Reports (2020-23)	Firm-level reports on decarboniza-tion projects	IAPMEI
Industry level indicators (2022)	Location, sector, VAB, Employment	INE
CO_2 Emissions (2019)	CO_2 emissions by sector	APA
Population (2021)	Density, urban population	INE

Source: SUS2TRANS

With this information, we adopt a methodology roadmap as depicted in Figure 1. Our analysis begins with a corpus of 2,793 PT2020 project descriptions. To enable nuanced comparisons, we employ a standard sentence transformer model (Reimers and Gurevych, 2019) to encode these descriptions, along with decarbonization definitions and pathway descriptions, into high-dimensional vector representations.

To identify decarbonization-related projects, we calculate the cosine similarity between each project's encoding and the decarbonization definitions (Cer et al., 2017). Based on an intersection analysis, we select the subset of projects with the balanced highest similarity scores for both decarbonization definitions and pathway descriptions.

Figure 1. Methodology roadmap



Source: own elaboration

For these selected projects, we employ a multi-label classification approach to attribute them to specific pathways (Tsoumakas and Katakis, 2007). We divide each project description into sentences and encode them individually. We then compute cosine similarity scores between each sentence encoding and the six predefined pathway descriptions. To assign pathways to a project, we consider the top similarity scores across all sentences in that project. The most frequent pathway within these top scores determines the project's classification. This method allows for multiple pathway attributions when appropriate, as projects may encompass strategies aligned with more than one pathway. By focusing on the highest similarity scores, we ensure that projects are classified according to their most significant decarbonization strategies, while the sentence-level analysis captures the nuanced content within each project description.

The second stage of the research involves examining the relationship between firm characteristics and their decarbonization strategies. By grouping firms based on size, industrial sector, and location, this study explores how regional specialization and urbanization influence the firms' willingness to decarbonize and the types of decarbonization pathways they adopt. Special attention is given to comparing firms in core urban regions with those in peripheral areas.

To deepen the analysis, firms' decarbonization strategies were categorized according with the six pathways previously identified. By comparing the prevalence of these strategies across regions, this study identifies patterns that highlight regional unevenness in decarbonization efforts.

Results

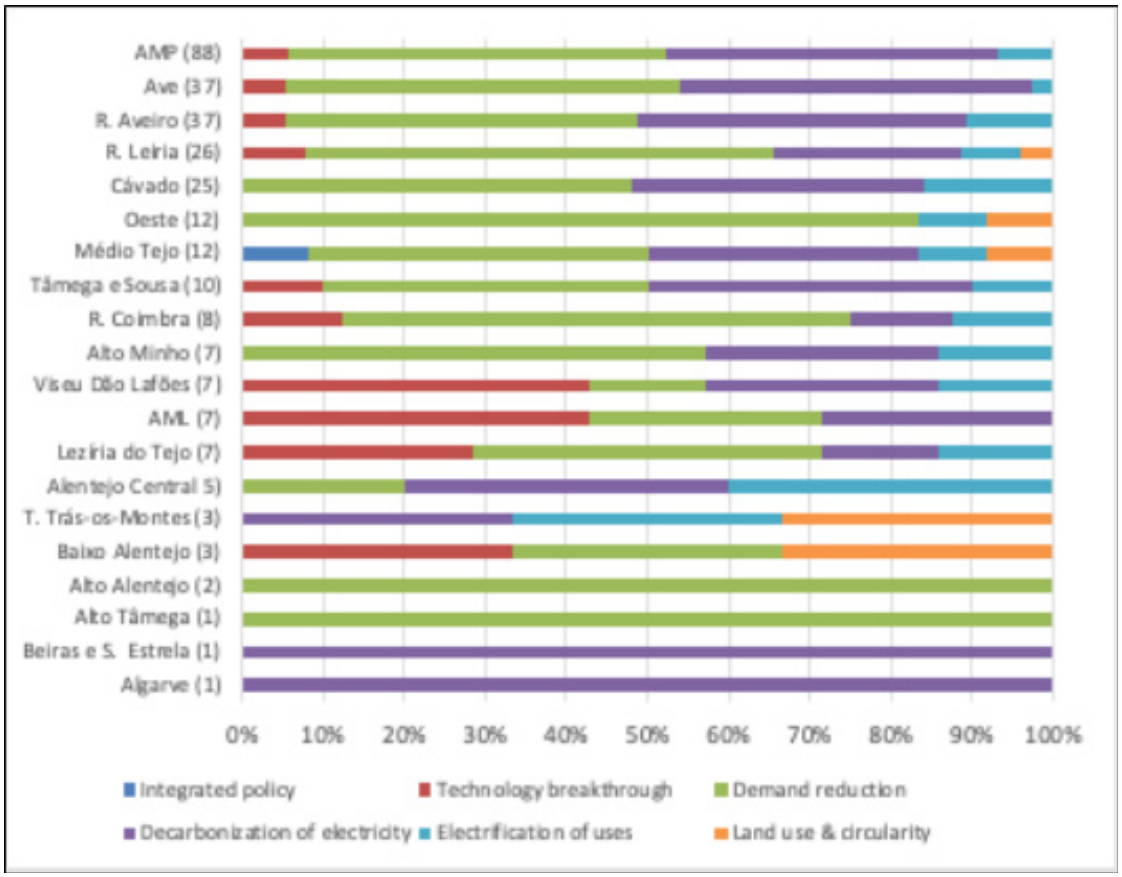
This section presents a descriptive analysis of the decarbonization strategies adopted by firms funded under the PT2020 program, focusing on regional differences, firm-level and sector-level characteristics, and the specific decarbonization pathways pursued. Overall, the proportion of decarbonization projects is modest, corresponding to less than 10 % of the 2.793 firms analysed. The results highlight the uneven adoption of decarbonization practices across different regions of Portugal, with a particular emphasis on the divide between core urban areas and peripheral regions.

Regional distribution of decarbonization projects

The distribution of projects reflects both the spatial distribution manufacturing activities and the EU funding allocation according to the European cohesion policy. Firms engaging in decarbonization projects are clearly concentrated in Portugal's urbanized regions, particularly in the Porto metropolitan area, which accounts for a significant share of firms funded by PT2020.

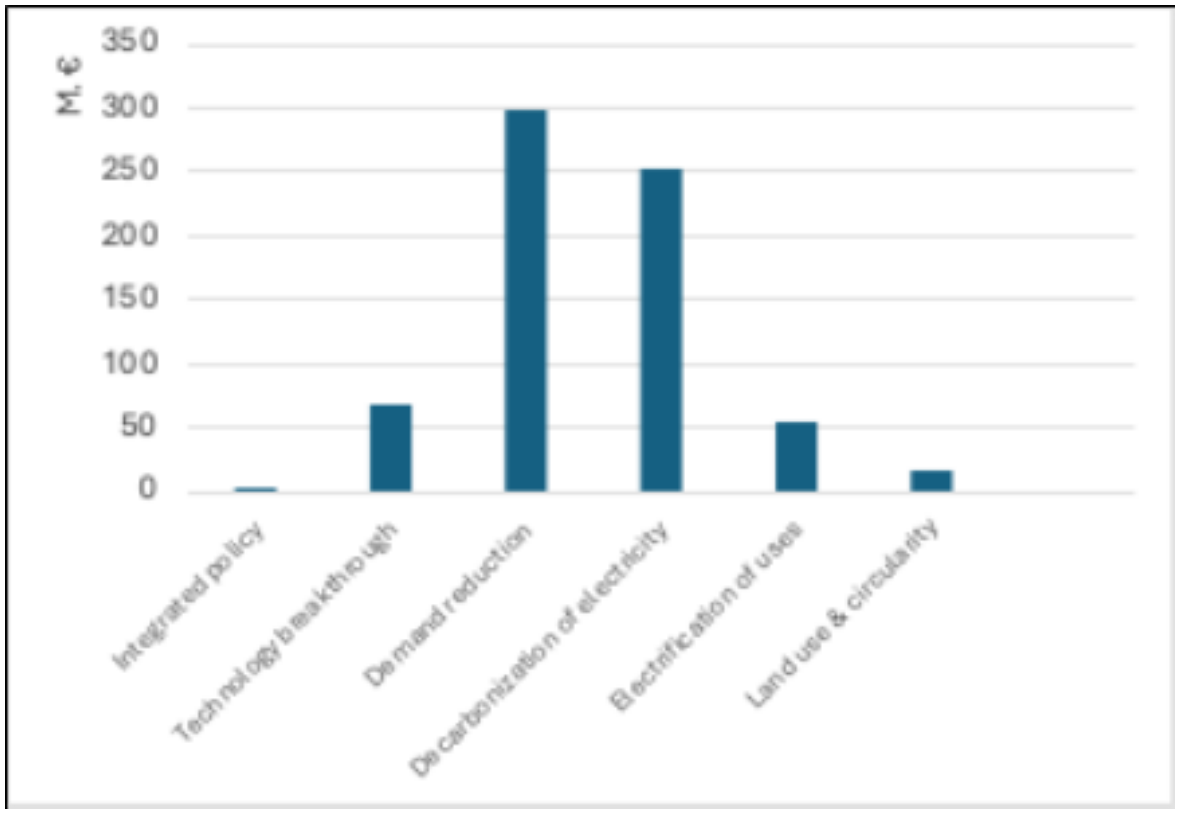
Figure 2 depicts the regional differentiation of volume of investment by firms per decarbonization pathway. While peripheral regions are involved, they exhibit fewer projects, likely due to their weaker industrial bases and lower innovation capacities. Although Lisbon is a highly advanced industrialized area and a core region, the lower-than-expected number of decarbonization projects can be attributed to its limited access to EU funding, as it is classified as a more developed region under EU cohesion policy and thus receives less financial support compared to less developed regions. Demand reduction and decarbonization of electricity are the mains areas of investment concentration, representing 43,5 % and 36,5 % of total projects, respectively (Figure 3).

Figure 2. Breakdown of decarbonization projects by pathway and region



Source: PT2020, IAPMEI

Figure 3. Distribution of decarbonization investment by decarbonization strategies



Source: PT2020, IAPMEI

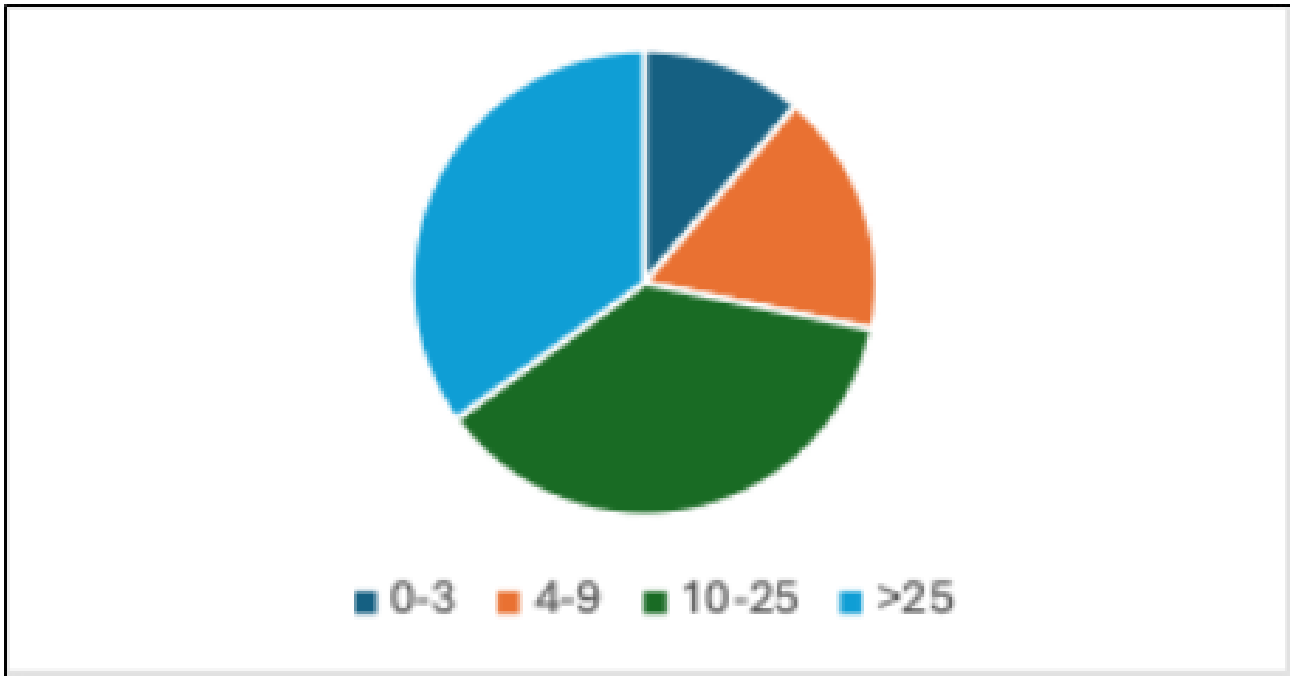
The distribution of the firms' projects by decarbonization pathways follows a stable pattern at the regional level, especially in the regions with more projects. These regions show similar structures of CO_2 emissions, with a very high share of heat (in buildings) and electricity production and industry. Interestingly, the other regions with 10 or less projects funded (right of Viseu Dão Lafões) show much higher heterogeneity in terms of decarbonization pathways. Contrary to the previous group, road and other sources dominate the structure of CO_2 emissions.

Firm size and sectoral distribution of decarbonization projects

Another critical aspect of the analysis is the relationship between firm size and decarbonization strategies. Figure 3 shows that one third of the firms with decarbonization projects supported by PT2020 are micro companies (less than 10 employees). Another third are small companies (between 11 and 50 employees) and the remaining third includes small, medium and large companies. However, this data does not show the amount of funding among the groups—see Section 5 for more details. The following figure presents a breakdown of decarbonization strategies by firm size (small, medium, large) (Figure 4).

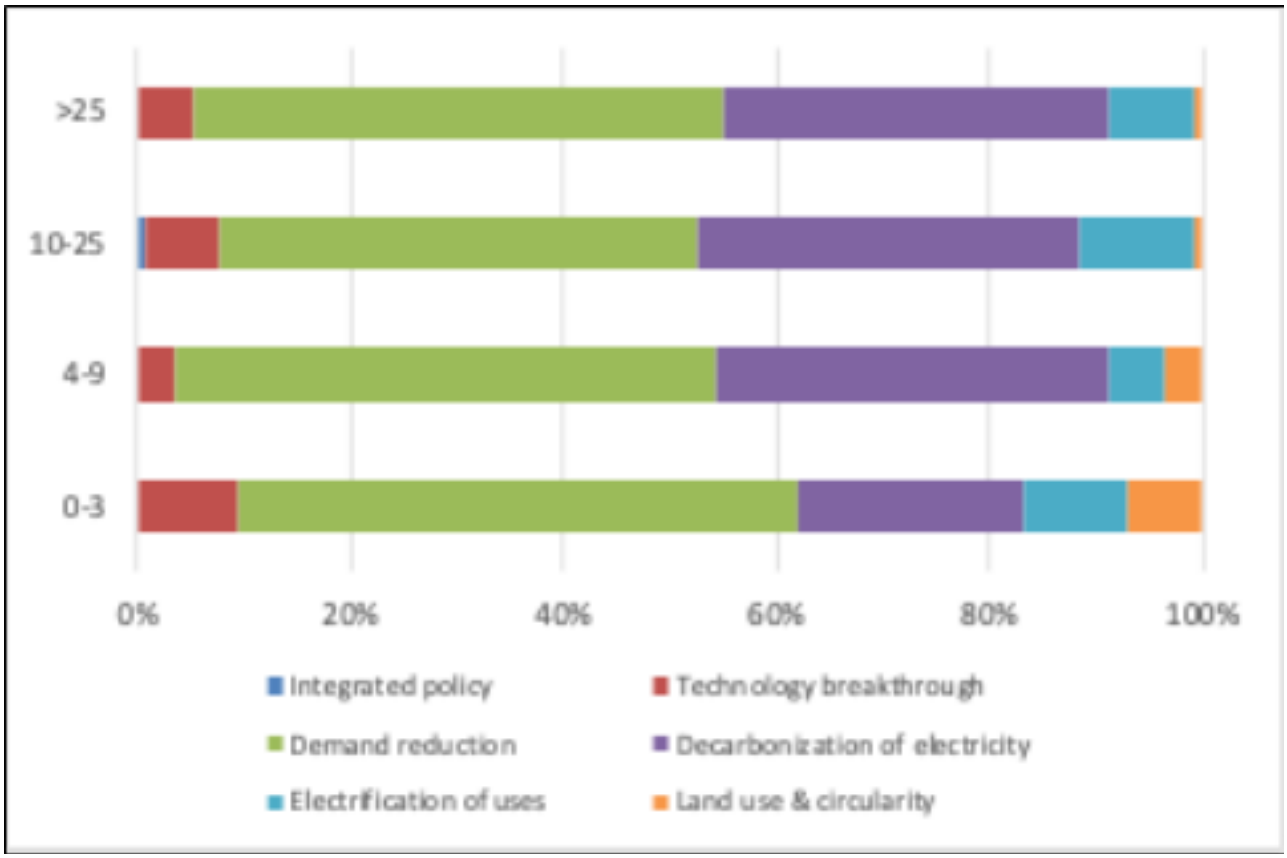
This breakdown indicates that firms, regardless of size, are generally more inclined toward demand reduction (Figure 5). Comparatively, micro firms tend to invest more in technological breakthroughs but less in electricity decarbonization, while large firms place greater emphasis on both demand reduction and the decarbonization of electricity.

Figure 4. Decarbonization projects by firm size (number of employees)



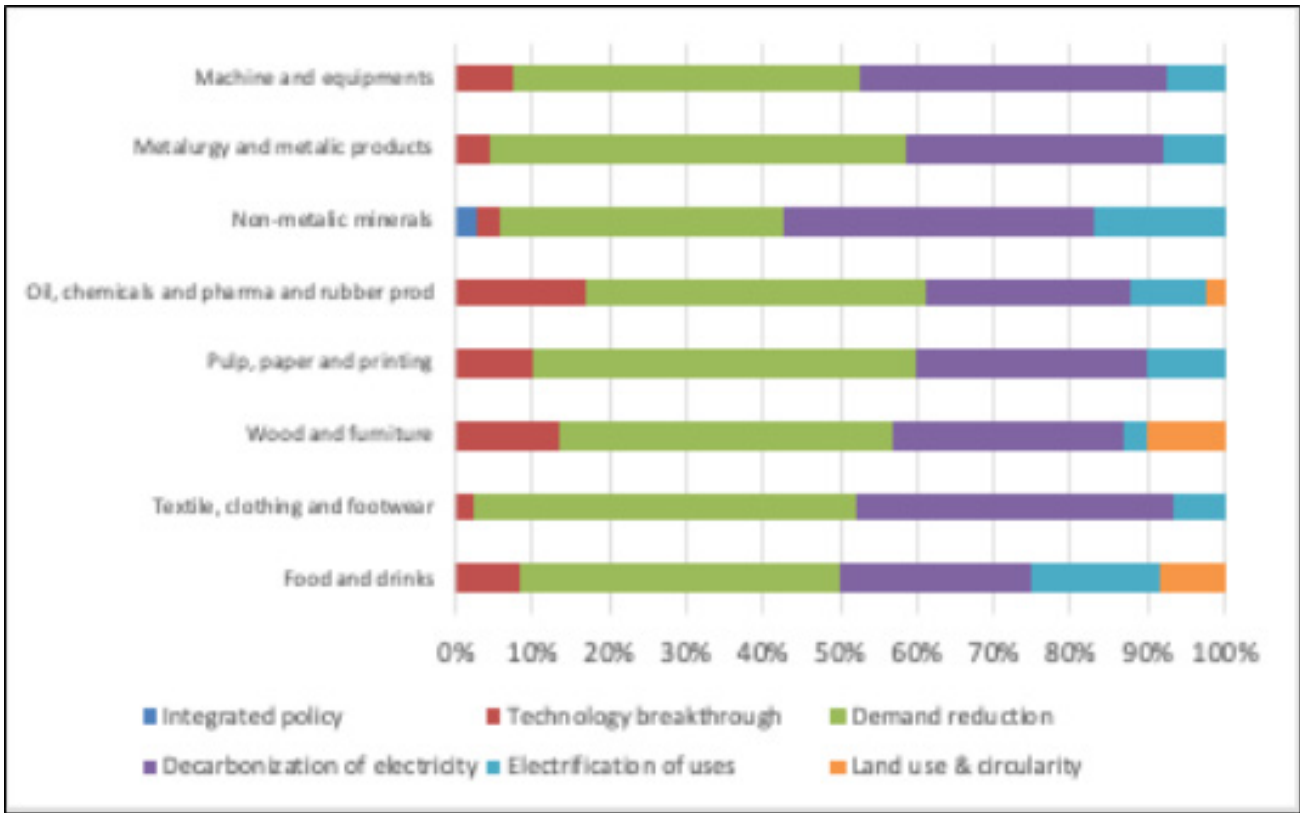
Source: PT2020, IAPMEI

Figure 5. Decarbonization strategies by firm size



Source: PT2020, IAPMEI

Figure 6. Sectoral distribution of decarbonization projects



Source: PT2020, IAPMEI

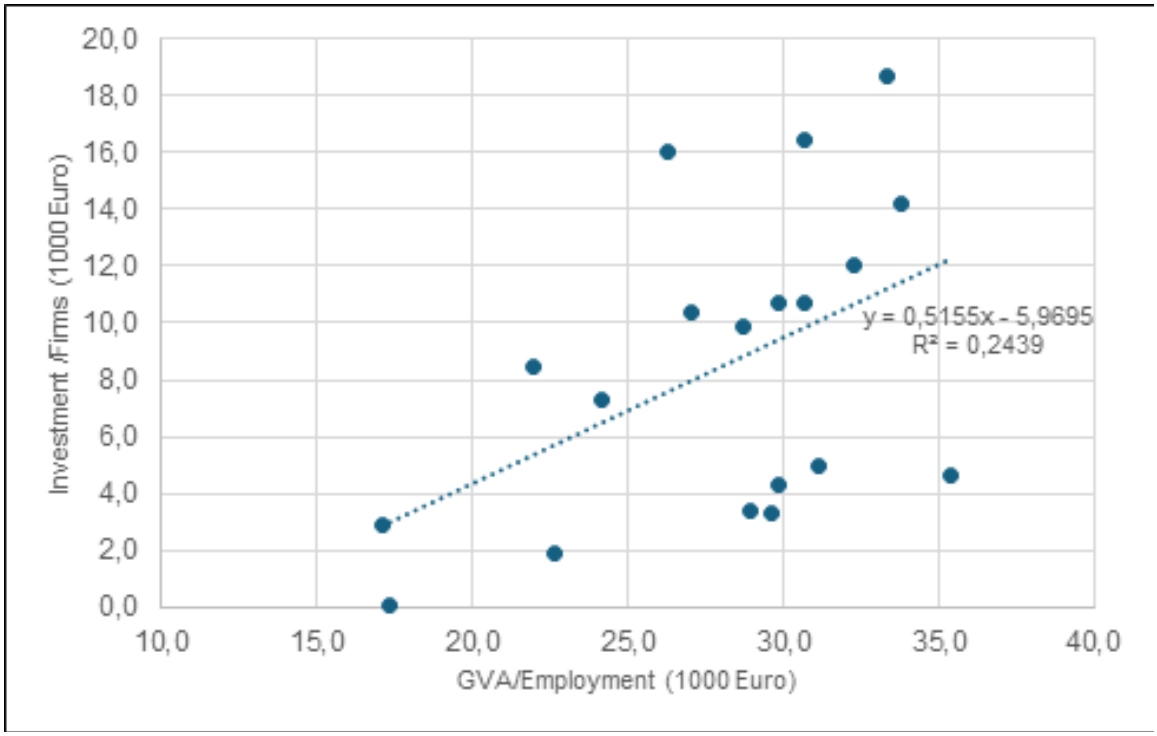
Majority of sectors show typical decarbonization pathway, focusing on demand reduction. However, sectoral analysis reveals sensible variations in the type of decarbonization strategy pursued by firms (Figure 6). Sectoral specialization plays a critical role in determining the type of decarbonization pathway a firm is likely to pursue. The analysis shows that textiles and clothing and machinery and equipment sectors tend to focus more on demand reduction or decarbonization of electricity, reflecting their reliance on energy-intensive processes. Comparatively, chemical manufacturing shows a stronger inclination toward technological breakthroughs, as this sector faces stricter regulatory controls and requires innovative solutions to meet emission reduction targets. On the other way, sectors like wood and paper show high dispersion in decarbonization strategies, including the adoption of land use and circularity pathways, which are aligned with resource efficiency and circular economy principles.

Discussion

The regression analysis highlights important relationships between various factors—such as capital intensity, CO_2 emissions, and regional industrial structure—and the adoption of decarbonization strategies in different manufacturing branches. These findings have significant implications for understanding the conditions under which firms are more likely to engage in decarbonization efforts and the type of strategies they adopt. Considering the specific case of the Lisbon metropolitan area in relation to EU funding access, we exclude this region from regression analysis to avoid potential bias.

The regression analysis reveals a positive correlation between capital intensity in manufacturing and the number of decarbonization projects and investment per firm. Regions with a higher concentration of capital-intensive industries — industries that require substantial capital investment — tend to invest more in projects aimed at reducing emissions (Figure 7).

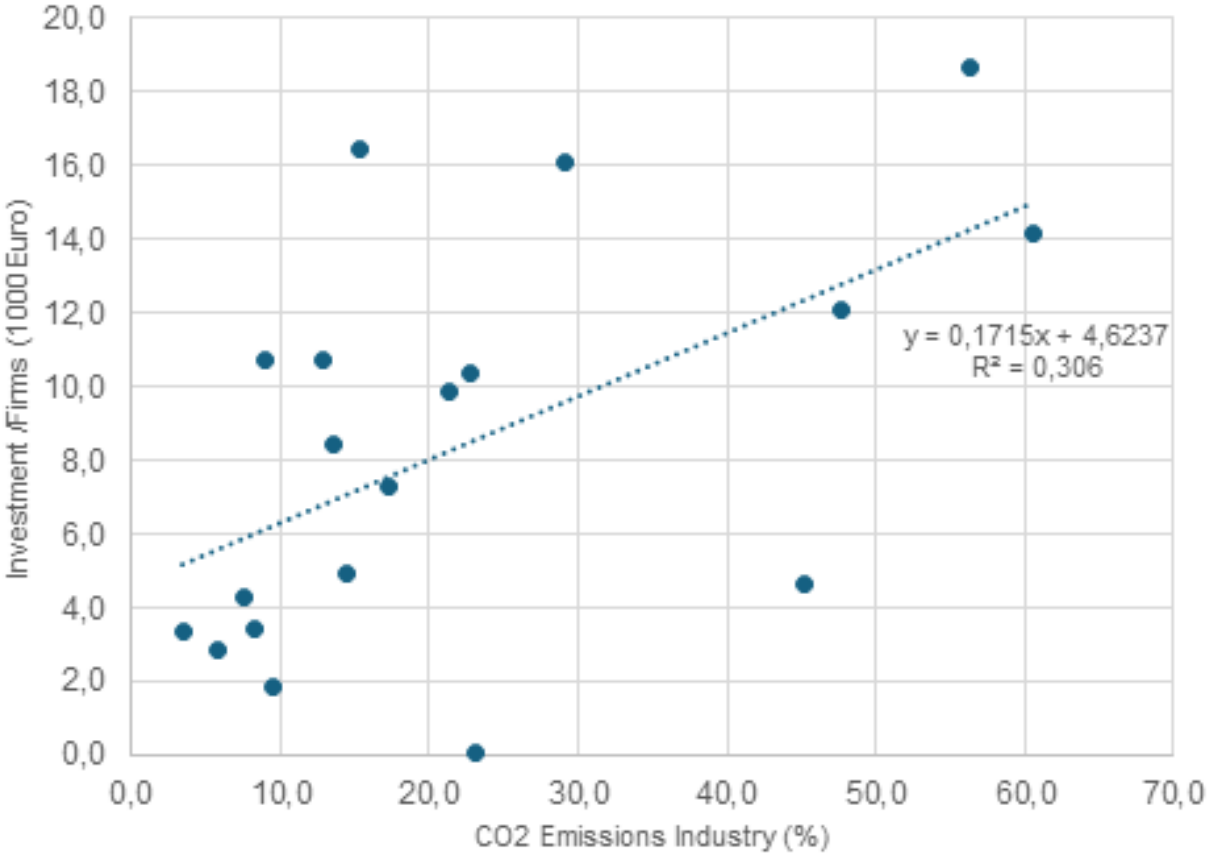
Figure 7. Firm productivity and decarbonization investments by region



Source: PT2020 and INE

(p-value is 0.0326, which is below the typical 0.05 significance level, suggesting that this correlation is statistically significant.)

Figure 8. CO_2 emissions and decarbonization investments by region



Source: PT2020, INE and APA

(p-value is 0.0138, which is below the 0.05 significance level, suggesting that this correlation is statistically significant.)

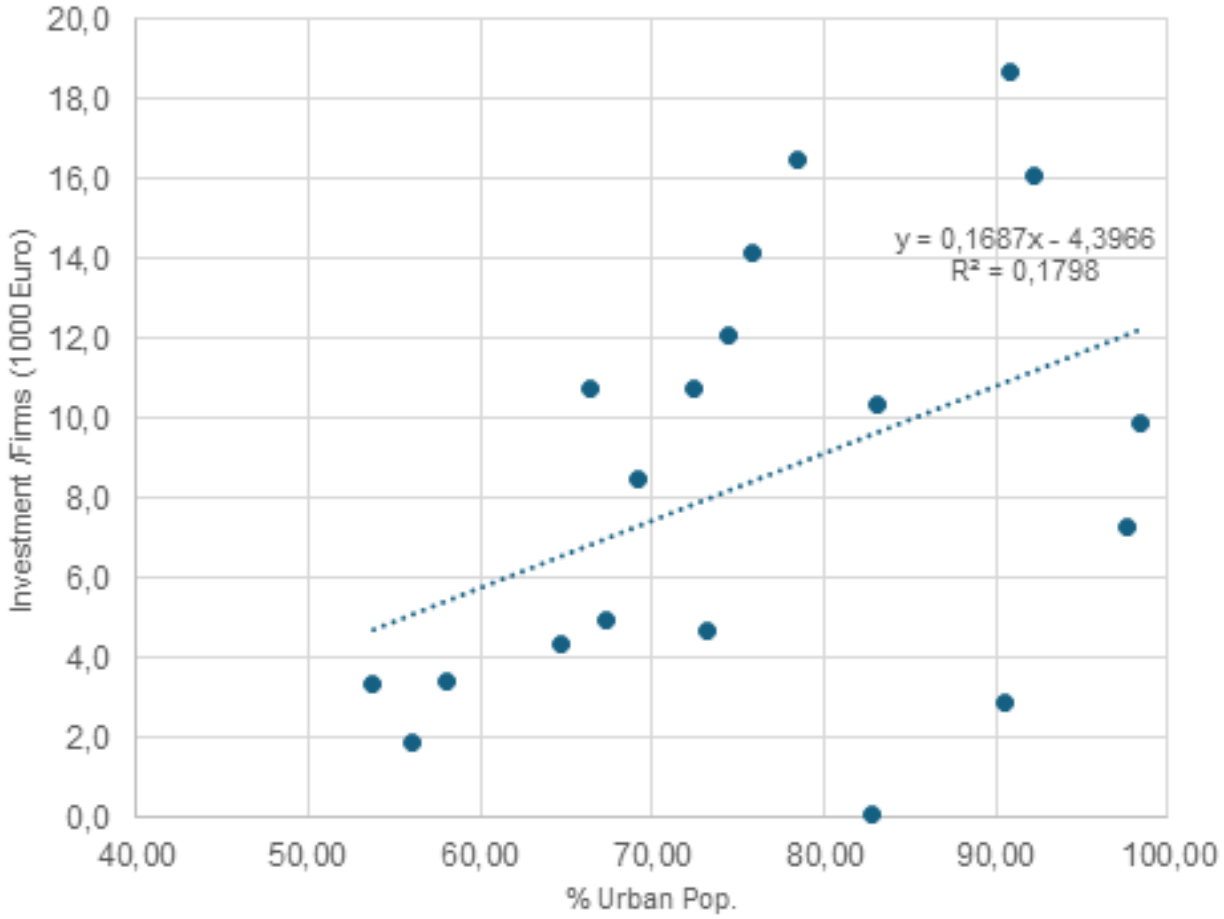
Furthermore, regions with higher CO_2 industrial emissions show a similarly positive relationship with the number of decarbonization projects (Figure 8). This suggests that firms in these sectors may be driven by regulatory pressures to reduce their carbon footprint. Also, the analysis shows that firms located in regions where the share of industrial CO_2 emissions is higher are more likely to invest in decarbonization projects ($r = 0.48$ for regions with above-average emissions vs. $r = 0.39$ for other regions). This demonstrates the role of environmental pressures as a key driver for decarbonization efforts. On the other hand, the findings suggest that sectoral CO_2 intensity—the emissions intensity of the industries themselves—does not play a decisive role in shaping the decarbonization investments of firms funded by PT2020. One possible explanation for this is that high-polluting industries often have access to alternative funding streams, including own financial resources, that are specifically targeted at their decarbonization needs.

The regression analysis highlights the significant impact of contextual factors on the decarbonization investments made by firms participating in the PT2020 program. One of the most prominent factors is industrial productivity, where firms located in regions with higher productivity and a higher concentration of CO_2 emissions from industrial activity tend to invest more in decarbonization projects. These correlations suggest that firms in these regions face greater regulatory and environmental pressures to reduce their carbon footprint, prompting them to utilize available funding, such as PT2020, to implement emission reduction strategies.

However, while industrial productivity and CO_2 emissions clearly is associated with decarbonization investments, the analysis shows a slightly less pronounced role

for urbanization (Figure 9). The location patterns of specific industries may dilute the expected impact of urbanization on decarbonization efforts. In other words, the types of industries located in urban regions might not align closely with sectors facing the greatest decarbonization pressures, thus leading to a less significant relationship between urbanization and investment. Furthermore, regions with lower levels of urban development and population density also concentrate more intensive CO_2 activities, therefore explaining the less clear correlation with decarbonization investments.

Figure 9: Urban population and decarbonization investments by region



Source: PT2020 and INE

(p-value is 0.0692, which is above the 0.05 significance level, suggesting that this correlation is not statistically significant at the 5% level)

Table 3. Correlation Matrix Coefficients

	GVA/ Employment	% Industry CO_2 emissions	% Urban Population
Invest/Firms	0.493 (p-value = 0.0326)	0.553 (p-value = 0.0138)	0.424 (p-value = 0.0692)

Source: PT2020, INE and APA

In summary, while contextual factors such as industrial productivity and regional CO_2 emissions play a significant role in decarbonization investments, the roles of urbanization and sectoral CO_2 intensity are less clear (Table 3). The complexity of industry location patterns and the availability of other funding sources for high-emission sectors likely explain these nuances in the data.

Conclusion and policy implications

The findings from this study emphasize the importance of contextual factors, such as regional industrial productivity and CO_2 emissions, in shaping decarbonization investments. Firms located in regions with higher industrial productivity and greater CO_2 industrial emissions concentration tend to invest more in decarbonization projects supported by the incentive systems of PT2020. This reflects the influence of both market pressures and regulatory frameworks, which are stronger in these regions due to their high pollution levels.

However, the role of urbanization remains ambiguous. The analysis reveals a moderate positive relationship between urbanization and decarbonization investments, though specific industry location patterns complicate this dynamic. Urban areas, despite their concentration of industrial activity, do not necessarily lead in all types of decarbonization strategies, possibly due to the type of industries located within these regions. Given the role of the Lisbon metropolitan area within the national urban system, its limited access to EU funding led to its exclusion from the analysis, which may explain why urban contextual factors appear less significant.

Another key finding is the limited relevance of industrial CO_2 intensity on decarbonization investments under PT2020. This may be due to high-emission industries accessing other funding streams specifically designed to address their needs. For instance, certain high-polluting sectors may receive direct support through specialized environmental funds, reducing their reliance on general programs like PT2020.

The results of this study have several implications for policymakers aiming to promote decarbonization across different industrial sectors and regions:

a. Fostering Support for High-Emissions Regions

Regions with higher industrial CO_2 emissions show a greater tendency to invest in decarbonization, suggesting that policies should further enhance this trend. These areas require continued regulatory pressure and incentives to accelerate decarbonization in high-emission sectors.

b. Supporting Peripheral Regions

The findings indicate that peripheral regions are lagging in industrial decarbonization strategies, emphasizing the need for place-sensitive policies. Given their less advanced industrial structures, these areas may require tailored incentives to overcome barriers to adopting green technologies and to implement more incremental or less speculative solutions. This could involve improving access to innovation networks and offering financial support to micro, small, and medium-sized enterprises, which often face challenges in engaging with sustainability transitions.

c. Industry-Specific Needs

Different sectors adopt different decarbonization pathways, with sectors like textiles and machinery focusing more on demand reduction and electricity decarbonization, while the chemical sector leans toward technological breakthroughs. Policymakers should recognize these diversities and sectoral differences. It's important to ensure that that sectors with high intensity of CO_2 emissions per unit of product receive attention, particular in peripheral (less resourceful) regions.

Future research should focus on understanding how regional specialization and the internationalization of industries affect decarbonization investments. Additionally, exploring how specific regions — particularly those with less advanced industrial structures—can better engage in sustainability transitions will provide important insights for designing effective regional decarbonization policies.

Acknowledgments

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