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Cross-Sector Collaborations for Accelerating Energy and Digitalization Transitions

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Abstract The need to reduce carbon emissions to mitigate climate risks is a reality and demands urgent changes in how society engages with energy. Collaboration between sectors and research centers has proven to be an effective path to accelerate sustainability transitions. This work examines the characteristics of collaborations between research centers and several sectors in European Union (EU27) countries in the context of digital and sustainable energy transitions. Utilizing systematic literature review (SLR) and bibliometric analysis, the study explores collaboration dynamics across industry, commerce, services, government, and NGOs. A rigorous SLR process, conducted using the SCOPUS and Web of Science (WoS) databases, ensures methodological precision. The approach adopts Open Innovation Theory (OIT) and public-private partnerships (PPPs) strategy to analyze interactions among these actors. The results show that industry and government are the main sectors driving collaboration with research centers, while commerce and NGOs appear less engaged, revealing opportunities to expand collaborative ecosystems. The findings highlight how open innovation, joint research initiatives, and PPPs can align research with societal needs and accelerate innovation. Preliminary results also emphasize the importance of policy support and stakeholder engagement to strengthen collaborations that foster innovation and support energy transition**.**

Keywords: Sustainable Energy Transition, Digital Transformation, Research Center, Cross-Sector Collaboration, Open Innovation Second Keyword.

1 Introduction

The sustainable energy transition (SET) and the digital transition (DT) play a key role in reshaping the way modern society engages with energy. These segments are redefining the technological and institutional structures that support innovation, governance, and global economic development. Their importance in creating both opportunities and challenges for low-carbon development grows as society demands stronger climate action while safeguarding economic growth.

SET is understood as a systemic shift from Carbon-based fuels to renewable and more efficient alternatives (Calvin et al., 2023). This transformation occurs as digitalization, with capabilities such as IoT and AI, supports the development of SET through, for example, real-time monitoring and predictive maintenance. These innovations make it possible to increase energy efficiency, reduce consumption, and accelerate the SET.

In this context, collaboration between economic sectors and research centers emerges as a key factor in driving innovation and promoting systemic change (Costa et al., 2025). Research centers play a key role in supporting knowledge generation, technology development, and management processes. The involvement of these centers in partnerships with industry, commerce, services, government, and non-governmental organizations (NGOs), especially when analyzed through the lens of public-private partnerships (PPPs), enhances results, strengthens innovation, and influences the pace and direction of energy and digitalization.

The industrial sector, for example, is among the largest energy consumers and is a key player in decarbonization efforts (Calvin et al., 2023). Its involvement in research collaborations can result in cleaner production processes, energy-efficient technologies, and more effective circular models.

Other sectors, such as commercial and service, although often overlooked, are showing growing interest in efficient and digitalized energy solutions to optimize operations and reduce their environmental footprint. Government agencies, such as regulators and financiers, exert significant influence on the collaboration and innovation process. NGOs also contribute by promoting inclusive and equitable transitions, facilitating community engagement, and partnerships aligned with broader social goals.

Despite the growing recognition of the need for collaboration, significant questions remain which made us define the following research questions: RQ#1: What are the dominant themes shaping research center–sectors engagement to foster collaboration among stakeholders in the context of the sustainable energy and digital transitions? RQ#2: Which sectors show the greatest willingness to collaborate on research for sustainable energy transitions? RQ#3: Which sectors are most engaged in digital transition research? Addressing these questions is essential for designing policies and institutional frameworks that support effective, scalable, and inclusive innovative ecosystems.

By exploring these questions, this article aims to identify the sectors that demonstrate the greatest willingness and capacity to engage in research-driven innovation, as well as the strategies that facilitate successful partnerships. In this way, the research contributes to a deeper understanding of cross-sector collaboration to accelerate innovative and sustainable solutions.

The next section presents the literature review, highlighting the main aspects of the research. The methodology then describes how the study was structured and conducted. The results present the main findings, answer the research questions, and offer new insights. Finally, the conclusions highlight the points that require greater attention from policymakers and indicate avenues for future research.

2 Literature Review

Understanding the functioning and dynamics of SET and DT as drivers of innovation requires careful analysis of the key concepts and collaborative structures that shape research and development ecosystems. This section presents the main collaboration strategies adopted by economic sectors and research centers from the perspective of Open Innovation Theory (OIT).

The expansion of SET (a systemic process of transformation of energy ecosystems, aimed at replacing fossil fuels with renewable alternatives) is considered a global priority, especially in EU-27, due to its potential to mobilize technological resources and promote institutional and behavioral changes, aiming to reduce carbon emissions and combat climate change (Calvin et al., 2023; Costa et al., 2022).

In this context, DT (incorporating advanced digital technologies such as artificial intelligence, big data, the Internet of Things, and automation) plays a prominent role in production, management, and social interaction processes (Costa, 2024; Stadtmann et al., 2023). In the energy sector, these technologies have the potential to optimize energy generation, transmission, distribution, and consumption, as well as enabling new business and governance models (Huang et al., 2021; Costa et al., 2022; Costa et al., 2023).

Within this context, innovative ecosystems emerge as interdependent networks of actors (companies, research centers, governments, and civil society organizations) that collaborate to generate knowledge and innovations, supported by the complementarity of skills and governance mechanisms (Sousa and Costa, 2022).

Naturally, research collaboration lies at the heart of these ecosystems, enabling different sectors and actors to share resources and capabilities to achieve innovation. In this sense, partnerships between research centers, sectors, and economic actors are especially relevant in transitional contexts, where the complexity of the challenges demands interdisciplinary and intersectoral approaches (Verreynne et al., 2025; Costa et al., 2017).

Extending this perspective to collaboration between economic sectors, it becomes clear that the innovation process is directly linked to factors such as technological intensity, regulatory pressure, and the perception of opportunities and risks. For example, the industrial sector tends to lead innovative projects focused on energy efficiency and the decarbonization of production processes. In contrast, the trade and services sectors turn into digital technology solutions to optimize operations, reduce costs, and minimize environmental impacts - especially in areas such as logistics, smart buildings, and data management (Yi et al., 2022; Osorno-Hinojosa et al., 2022).

Governments, acting as regulators and supporters of research, and NGOs, contributing local knowledge, social mobilization, and impact monitoring, also play strategic roles in this collaborative environment. Therefore, well-coordinated interaction among these actors is essential to foster collaboration and drive innovations that are both relevant and environmentally sustainable (Jiang and Ko, 2024).

However, successful collaboration between sectors and stakeholders relies on a wide set of theories and strategies. OIT, widely used in the context of collaborative ecosystems, argues that organizations should seek knowledge beyond their own borders to accelerate innovation processes (Heaton and Min, 2025). The OIT emphasizes that institutions should not depend solely on internal capabilities but should pursue partnerships, especially with research centers. It highlights the effectiveness of external collaborative approaches in transitional contexts, where the speed and complexity of change demand rapid, efficient solutions that can be achieved through shared information (Heaton and Min, 2025).

In the context of strategies used to foster collaboration, a wide range of options can be identified. Public-Private Partnerships (PPPs) - institutional mechanisms that enable cooperation between the public and private sectors in implementing projects of common interest - are widely applied in the fields of energy and digitalization. PPPs have been fundamental for enabling infrastructure investments, testing new technologies, and scaling innovative solutions, while also helping to align public policy objectives with long-term business strategies (Callens, 2022).

Another highly valuable strategy for fostering collaborative initiatives between research institutions and other stakeholders is the use of Joint Research Initiatives (JRIs). This approach involves collaborative arrangements among multiple actors aimed at developing applied knowledge and technological solutions. JRIs are particularly relevant in frontier areas, such as the integration of renewable energy and artificial intelligence, as they enable shared opportunities and reduced risks while building collective capabilities for all parties involved (Palazzolo et al., 2019; Tereshchenko et al., 2024).

A third strategy with significant impact on collaboration processes is the development of Innovation Hubs and Clusters (IHCs). These geographic or thematic environments bring together actors connected by common innovation interests. IHCs foster knowledge exchange, access to funding, network formation, and pilot-scale testing of solutions. In the context of SET and DT, IHCs have proven especially effective for facilitating technology transfer and strengthening the link between research and the market (Medina et al.,2023; Tereshchenko et al., 2024).

3 Methodology

This research investigates how research centers and several economic sectors collaborate through public-private partnerships (PPPs) to advance SET and DT by conducting a systematic literature review (SLR) and bibliometrics analysis (BA). The SLR method ensures a rigorous and transparent approach to reviewing academic literature by

requiring clearly defined selection, filtering, and synthesis criteria, which makes the review replicable and credible (van Dinter, 2021). Through this method, the study aims to consolidate existing knowledge, identify research gaps, and suggest directions for future work.

3.1 Database Design, Selection, and Data Collection

Both the SLR and bibliometric analysis were carried out using the Scopus and Web of Science (WoS) databases, both known for their comprehensive coverage of peer-reviewed research. The review process was structured in multiple phases: first, a preliminary review of the top five journals ranked by the SCImago Journal & Country Rank (SJR) helped identify relevant keywords and concepts. Next, a detailed search was conducted on WoS and Scopus. The search terms focused on key concepts identified during the preliminary review: “collaboration,”, “research center,” “education institutions”, “university,” “green transition,” “renewable energy transition,” “sustainable energy transition,” “clean energy transition,” “digitalization,” “digital transition,” “industry,” “company,” and “firm.” The final search query combined these terms: ("collaboration" AND ("education institutions" OR "university" OR "research center") AND ("green transition" OR "renewable energy transition" OR "sustainable energy transition" OR "clean energy transition" OR "digitalization" OR "digital transition" OR "industry" OR "company" OR "firm")). The results were exported in RIS format and then imported into a spreadsheet for processing.

This search retrieved 1,279 papers. Duplicates and invalid entries were removed to refine the dataset (357). Screening involved 922 papers and occurred in two stages: an initial review of titles and abstracts to filter out irrelevant articles, followed by a full-text screening to confirm alignment with the study’s scope. This process was guided by specific inclusion and exclusion criteria.

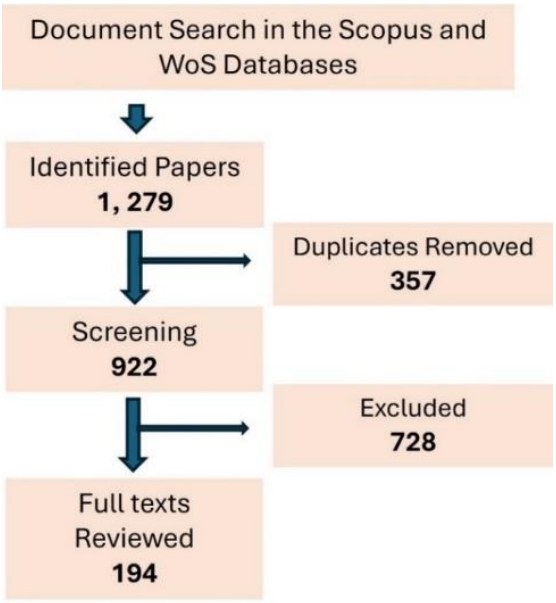


Figure 1. Research scheme to select the papers to include in the literature review
Source: Elaborated by the authors.

Articles were included if they:

- were written in English,
- were indexed in WoS or Scopus,
- were published between 2019 and 2024,
- used primary data,
- refers to EU-27 countries, and
- specifically addressed collaboration between research institutions and sectors on SET or DT.

Articles were excluded if they were duplicate, and if they did not meet the inclusion criteria or lacked relevant discussion of strategies or sectors. Of the 922 records screened 728 were excluded resulting in 194 articles selected for final analysis (Fig. 1)

3.2 Sector and Segment Classification

To increase analytical clarity, the selected articles were grouped into six sectors: (1) Industry, (2) Commerce, (3) Services, (4) Government, (5) Non-Governmental Organizations (NGOs), and (6) Other. This classification reflects the diverse roles these sectors play in driving collaboration and innovation.

Segmenting the analysis by SET and DT highlights their importance for sustainable socio-economic development. SET supports decarbonization efforts, while DT drives

efficiency and technological progress, promoting modernization and collaboration across industries. This focus enables the study to examine how these collaborations shape sustainability outcomes.

3.3 Theoretical Foundations for Collaboration and Innovation

Theoretical frameworks are crucial for understanding how sectors engage in collaboration, as they help identify key factors, compare examples, interpret findings, and inform policy (Layani et al., 2024). This study uses OIT (Heaton and Min, 2025) to analyze the interactions between sectors and strategies in collaborative processes. OIT explains how partnerships can be structured and managed to strengthen knowledge creation and foster innovation. It aligns research center activities with sectors' needs and broader societal goals. Here, SET refers specifically to renewable technologies such as wind and solar, with an emphasis on collaborations that drive clean energy initiatives.

3.4 Analytical Techniques

To examine how different sectors align with the principles of OIT, a correlation analysis was conducted after a preliminary binary (0/1) coding of the data.

This analysis examined the relationship between sectoral involvement (specifically Industry, Commerce, Services, Government, and NGOs) and the application of OIT across a sample of 194 articles. Each sector was coded using a binary system (1 = sector addressed in the article; 0 = not addressed). A heatmap was generated to visualize the strength and direction of the correlations between sectoral presence and OIT-related content, with correlation coefficients ranging from -1 to +1. This method enabled the identification of sectors most closely associated with OIT, offering insights into patterns of collaboration and the theoretical relevance of OIT across different institutional contexts.

The heatmaps were produced in Python using the Seaborn and Matplotlib libraries within a Jupyter Notebook environment. These tools made it possible to clearly visualize the correlation patterns between the theoretical framework and sectoral engagement, supporting a more detailed interpretation of thematic alignment in the study. To maintain methodological focus, the 'Other' category within the sectoral classification was excluded from the correlation analysis. This category included broad or ambiguous cases that could not be consistently interpreted across the sample.

4. Results

This section presents revealing results on the varying degrees of sectoral engagement in the sustainable and digital energy transitions, offering insights into how each sector contributes to collaboration between research centers and economic actors.

4.1 Bibliometric Analysis of Engagement Themes in Energy and Digital Transitions

This section addresses *RQ#1. What are the dominant themes shaping research center–sectors engagement to foster collaboration among stakeholders in the context of the sustainable energy and digital transitions?*
Figure 2 presents a word cloud that visually highlights the most frequent and relevant concepts found in studies of collaboration between economic sectors and research centers regarding the sustainable energy transition and digital transformation. The size of each word reflects its prominence (larger words represent higher importance or frequency in the dataset). The most prominent term, Research Centers-Sectors engagement, underscores the central role of partnerships between research centers and economic sectors

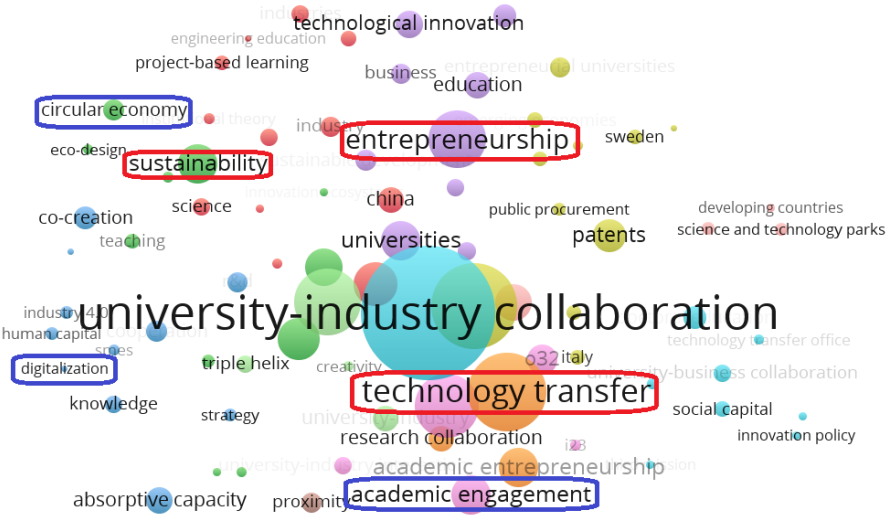


Figure 2. Word Cloud of Collaboration Themes in Energy and Digital Transitions
Source: Elaborated by the authors.

Other key terms such as Technology Transfer, Entrepreneurship, and Sustainability point to the focus on innovation and responsible development. Supporting concepts like Digitalization, Circular Economy, and Academic Engagement reveal a multidimensional approach to collaboration. Overall, the word cloud illustrates the vital role of cross-sector partnerships in advancing both digital and sustainable transitions.

4.2 Sectoral Roles in Sustainable Energy Transition Collaboration

This section addresses *RQ#2. Which sectors show the greatest willingness to collaborate on research for sustainable energy transitions?*
Figure 3 shows that the industry sector plays a dominant role, accounting for 57% of collaborative efforts in SET collaborative studies. This underscores its central contribution to driving innovation, deploying new technologies, and investing in sustainable energy solutions in response to societal demands for industrial decarbonization. The Government sector follows, with 20% of the papers, reflecting its crucial role in policymaking, funding, and regulatory support. The Service sector appears in about 9% of the papers, likely through consultancy, logistics, and energy-related services.
In contrast, Commerce (7%) and NGOs (7%) show relatively low levels of involvement. This may be due to their limited direct participation in energy R&D or infrastructure projects, although their contributions to raising awareness, advocacy, and market facilitation remain significant.

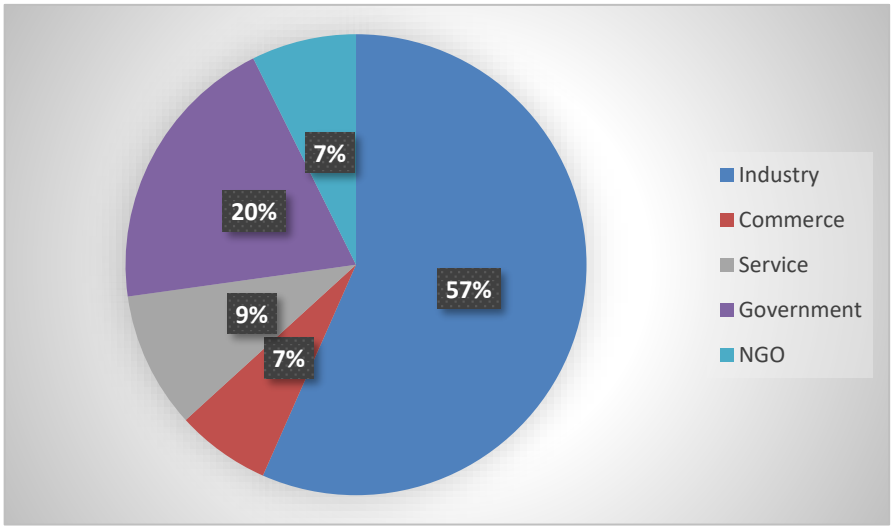


Figure 3. Sectoral Engagements to Sustainable Energy Collaboration
Source: Elaborated by the authors.

4.3 Sectoral Roles in Sustainable Energy Transition Collaboration

This section addresses *RQ#3. Which sectors are most engaged in digital transition research?*

Regarding DT involvement, Figure 4 shows that the industry sector contributes the most to digital actors' collaborations, accounting for 51% of the total. This underscores its key role in driving technological innovation, developing digital infrastructure, and advancing applied research. This is particularly relevant within the EU-27 context, where there is strong momentum to digitalize diverse economic activities. The Services sector comes in second with nearly 20% of the papers covering this sector, likely due to its role in IT services, digital platforms, and support systems, which are increasingly prioritized by different industries. The Government sector accounts for 17%, highlighting its crucial function in policy development, research funding, and digital governance. In contrast, NGOs (7%) and Commerce (6%) show lower levels of participation, possibly due to more limited direct involvement in digital R&D or a greater focus on operational rather than strategic innovation.

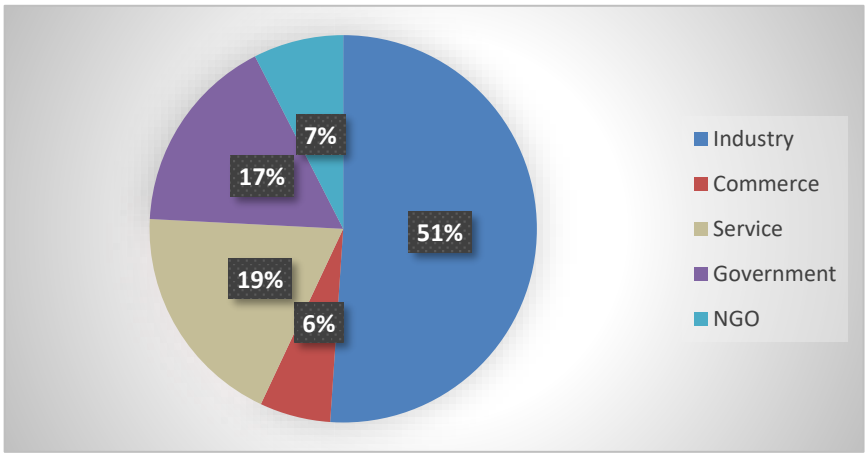
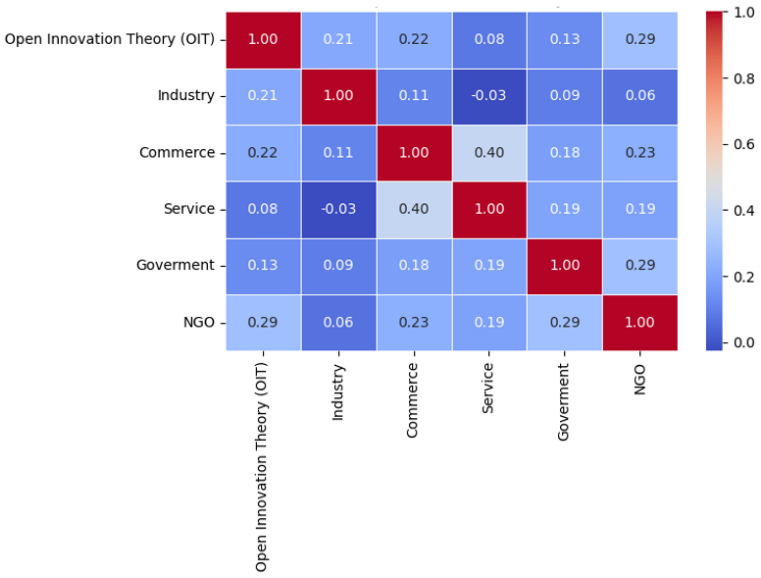


Figure 4. Sectoral Engagements to Sustainable Energy Collaboration
Source: Elaborated by the authors.

4.4 Open Innovation Theory and Sectoral Participation in Sustainable Energy Transition

The heatmap (Figure 5) illustrates the correlation between OIT and five sectors: Industry, Commerce, Service, Government, and NGO. Each cell shows a correlation coefficient ranging from -1 to 1, where values closer to 1 indicate a strong positive linear association. In this case, NGO shows the highest positive correlation with OIT (r=+0.29) followed by Commerce (r=+0.22) and Industry (r=+0.21). Government and Service show the lowest correlations (+0.13 and 0.08 respectively). This pattern highlights that OIT is primarily applied in contexts involving non-governmental organizations, industrial and commerce collaboration. The associations are however moderate (below 0.3).

Although NGO and Commerce show the highest correlations with OIT in this dataset, the values remain moderate (below 0.3), suggesting only limited linear associations. One possible explanation is that these sectors may be underrepresented in the sample, which could affect the statistical strength of the correlations. Additionally, their innovative activities may not always align with the structured, collaborative frameworks emphasized in OIT (commerce often focuses on being market-driven, while NGOs may prioritize social impact over formal research partnerships).



Source: Elaborated by the authors.

Figure 5. Correlation between Open Innovation Theory (OIT) and economic sectors regarding Sustainable Energy Transition
Source: Elaborated by the authors.

5. Conclusion

This study demonstrates that cross-sector collaboration between research centers and economic actors remains a key driver for advancing the digital and sustainable energy transition essential to supporting decarbonization goals and mitigating climate change. The results reinforce that the challenges of decarbonization and digitalization require collective action through well-structured interactions capable of driving innovation.

The findings confirm the leading role of industry, supported by governments, services, and other sectors, in driving research-based innovation for digital and low-carbon solutions. The prominence of topics such as research center–economic sectors collaboration illustrates how open innovation structures help align research results with practical needs, ensuring innovation and promoting the circulation of knowledge across institutional boundaries.

By connecting empirical evidence with Open Innovation Theory, this research highlights the relevance of strategies such as public–private partnerships and joint research initiatives that contribute to innovation and support social and economic objectives.

However, the lower representation of commerce, NGOs, and other potential contributors suggests that there are still opportunities to expand and balance collaborative ecosystems. Future research could further investigate the engagement of underexplored sectors and broaden the scope to other geographic regions to capture diverse contexts, institutional capacities, and governance approaches.

Some limitations were because several studies did not clearly specify the strategies adopted, which required more detailed reading and interpretation and made the review process more complex and time-consuming. Therefore, this study shows that accelerating sustainable and digital transitions depends not only on technological advances but also on robust, interconnected collaborative networks among diverse actors. Strengthening these networks through open innovation and inclusive strategies will be essential for achieving resilient, low-carbon development pathways aligned with global climate ambitions.

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