Evaluating Policy Orientation and Stakeholder Engagement in the EU's Green Initiatives for Industry 4.0 Adoption in SMEs: A Systematic Literature Review

Mansoor Ekrami[1], Miklós Losoncz[2], Dr. Harshavardhan Reddy Kummitha[3]

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ABSTRACT

This systematic literature review explores the European Union's policy landscape and stakeholder engagement in fostering Industry 4.0 adoption in Small and Medium-sized Enterprises (SMEs), with a focus on green initiatives. Rigorous methodology, combining electronic database searches and manual exploration, is employed to assess policy orientations and stakeholder dynamics. Findings highlight key orientations, including modernization, circular economy, and digital sovereignty. Stakeholder engagement emerges as a crucial factor in shaping effective and sustainable policies. This research contributes valuable insights for policymakers, industry stakeholders, and academia, offering a nuanced understanding of the European Union's strategic approach to integrating green initiatives in Small and Medium-sized Enterprises' Industry 4.0 adoption.

Keywords: EU Green Initiatives, Policy Orientation, Stakeholder Engagement, Industry 4.0, SME

Introduction

The advent of Industry 4.0 has ushered in a transformative era for businesses globally, characterized by the integration of digital technologies into manufacturing and production processes (Mourtzis et al., 2022). This revolution holds particular significance for Small and Medium-sized Enterprises (SMEs) within the European Union (EU), which are pivotal to the economy, innovation, and employment (Klein & Todesco, 2021). The EU's policy orientation towards green initiatives in the context of Industry 4.0 is not just a matter of technological advancement but also of sustainable development and inclusive stakeholder engagement (Tang et al., 2022). This systematic literature review aims to evaluate the direction, priorities, and stakeholder involvement set by policies related to the EU's approach towards green initiatives in Industry 4.0 for SMEs.

[1] Mansoor Ekrami, PhD student, Budapest Business University, Doctoral School of Entrepreneurship and Business, e-mail: Ekrami.mansoor.30@uni-bge.hu
[2] Miklós Losoncz, Professor, Budapest Business University, Faculty of Finance and Accountancy, Department of Finance and Accountancy, e-mail: Losoncz.Miklos@uni-bge.hu
[3] Harshavardhan Reddy Kummitha, Senior research fellow, Budapest Business University, Faculty of Commerce, Hospitality and Tourism Department of tourism and hospitality, e-mail: Kummitha.harshavardhan@uni-bge.hu

Industry 4.0, also known as the Fourth Industrial Revolution, emerged from the German government's strategy project to promote the computerization of manufacturing (Buchi et al., 2020). It quickly evolved into a global paradigm, encapsulating trends such as cyber-physical systems, the Internet of Things (IoT), and cloud computing. These technologies have rapidly developed, becoming increasingly accessible and affordable for SMEs, which form the backbone of the EU's internal market (Klein & Todesco, 2021). The importance of Industry 4.0 has been further amplified in the post-COVID-19 era, as businesses seek resilience and agility in their operations. The pandemic underscored the need for digital solutions that enable remote monitoring, predictive maintenance, and smart supply chains, which are essential for SMEs to adapt to new market realities and maintain competitiveness (European Commission, 2020).

The European Union, recognizing the critical role of SMEs in economic recovery and growth, has emphasized the need for policies that support the digital transition. One of the key strategies is the "Digitizing European Industry" initiative, which aims to foster the digital transformation of European industries. This initiative includes pillars such as the Digital Single Market, which promotes a unified digital market within the EU, and the establishment of Digital Innovation Hubs (DIHs) that provide support to firms in their digitalization efforts (Teixeira and Tavares-Lehmann, 2022). The EU's Digital Single Market strategy aims to open up digital opportunities for businesses and enhance Europe's position as a world leader in the digital economy. Policies are being crafted not only to drive technological adoption but also to ensure that this transition is aligned with the EU's ambitious climate goals, as outlined in the European Green Deal. The integration of green technologies in Industry 4.0 is seen as a strategic move to achieve a sustainable and inclusive digital economy, which is vital for the EU's long-term prosperity and environmental stewardship (European Commission, 2023).

Consequently, the emergence and rapid development of Industry 4.0 technologies have been pivotal in shaping the future of SMEs in the EU. The post-pandemic landscape has only heightened the importance of these technologies, as they offer solutions to the challenges of market volatility and the need for sustainable operations. The EU's policy-making efforts are thus focused on creating a conducive environment for SMEs to thrive in this new digital era, ensuring that technological progress goes hand in hand with ecological and social advancement. This systematic literature review will delve into these policies, evaluating how they are set to influence the trajectory of SMEs within the green and digital transitions of Industry 4.0.

Synthesis of the relevant literature

While there has been a growing focus on Industry 4.0 and the formulation of policies to promote it, there is still a relative scarcity of research on the formulation, implementation, and results of these policies. Teixeira and Tavares-Lehmann (2022) emphasized the need for comprehensive comparative studies that analyze the EU policies and strategies, as well as individual initiatives of EU countries, to understand the similarities and asymmetries among them. It also mentions the need for research on the impacts of the COVID-19 pandemic on the

implementation of Industry 4.0 and global value chains. Additionally, they suggest exploring the outcomes of the policies and evaluating the investments made in relation to Industry 4.0. In their research, the emerging concept of "Industry 5.0" and the need to focus on a more sustainable, resilient, and human-centric perspective of the industry is necessary.

The adoption of Industry 4.0 technologies is pivotal for the European Union's pursuit of the "twin" transition, which seeks to align digital transformation with sustainability objectives. This strategic approach underscores the interconnectedness of digitalization and environmental sustainability as mutually reinforcing elements shaping the EU's future (European Commission, 2021). The EU envisions leveraging digital innovation to enhance economic growth while concurrently addressing environmental challenges. However, SMEs encounter obstacles, including financial constraints, limited government support, technical skill shortages, and environmental culture barriers (Cronin & Doyle-Kent, 2022). Careful policy considerations and stakeholder engagement are imperative to navigate these challenges effectively. Notably, the integration of Industry 4.0 technologies has been identified as a substantial enabler of circular economy (CE) applications within European SMEs, suggesting that these technologies can significantly contribute to the individual strategies outlined in existing research frameworks (Findik et al., 2023).

The EU's technological-specific industrial policies, particularly those surrounding the deployment of 5G and 6G technologies, are critical to the digital transformation of industries, including SMEs (Rossi, 2023). The integration of these technologies is essential for the development of a digital single market and for ensuring the competitiveness of European businesses in the global market. However, the rollout of such technologies has not been without its challenges. Blind and Niebel (2022) discuss the complexities of the 5G ecosystem in the EU, highlighting the multitude of stakeholders and competing interests that make policy assessment challenging (Blind & Niebel, 2022). Their research focuses on identifying innovation 'failures' related to the 5G rollout and the policy measures implemented to address them, providing a tangible overview of the policy issues and the relevant 'failures' in the context of 5G rollout.

The circular economy is another cornerstone of the EU's green initiatives, with policies aimed at reducing waste and promoting resource efficiency. De Pascale's work on the circular economy implementation at the EU level offers a historical perspective and examines the current state and future directions of these policies (De Pascale, 2023). The circular economy demands the use of clean and affordable raw materials, and digital technologies are expected to create new business models, enhance productivity, and contribute to the de-carbonization of the economy (Liu et al., 2022). There is other research about the influence of the policy on the adoption of new technologies for example, Mallik's contribution to the academic and policy discourse provides a well-researched and documented analysis of the EU's policy landscape, using a variety of sources, including policy documents, industry reports, and expert opinions, to build a comprehensive picture of the EU's policy landscape (Mallik, 2023). The article identifies both challenges and opportunities for the EU's manufacturing industry, such as the need for breakthrough technologies and modernization to achieve climate neutrality goals. Paiho's article on the twin transition in the built environment addresses policy mechanisms,

technologies, and market views from a cold climate perspective (Paiho, 2023). It provides a comprehensive overview of the EU's policy landscape in the context of the green and digital transitions, significantly contributing to the understanding of the EU's strategic directions and the implications for its position in the global manufacturing industry.

The EU's policy-making process is characterized by a high level of stakeholder involvement (Ehlers et al., 2022), which is likely to have a significant impact on shaping policies related to the green and digital transitions. Brodny and Tutak (2023) found out that the success of EU initiatives in the Three Seas Initiative countries, which is crucial for the EU's development, appears to be significantly influenced by the level and nature of stakeholder engagement (Brodny & Tutak, 2023). This underscores the importance of such engagement, particularly by government entities, in advancing digital maturity.

The research design and methodology used in the articles to analyze EU policies and initiatives include a combination of qualitative and quantitative analyses, as well as the use of various scientific and analytical tools. Rossi's conceptual and analytical study draws on a wide range of secondary sources to analyze EU policies and initiatives, including studies and reports from the European Commission and other EU bodies, academic literature on industrial policy, competition, and innovation, and publications from strategic bodies and research institutes (Rossi, 2023).

In conclusion, the articles collectively underscore the EU's comprehensive approach to achieving a sustainable and digitally advanced economy, balancing technological innovation with environmental responsibility and societal needs. They highlight the EU's efforts to create a single digital market, formulate new legislations, strategies, and services to ensure product and data safety, and support investment in industry transition through various EU programs and funds.

The Role of EU Institutions in Crafting the Green Deal's Strategies

The institutions that make up the European Union are like a symphony, each with a different but harmonic function in the organization's commitment to a sustainable future. The European Commission is in charge of creating the legislative and policy framework for the EU's environmental goals. It is the architect of the European Green Deal, designing strategies that intertwine the threads of green policy with the fabric of economic growth and innovation. The Commission's proposals are then deliberated upon by the European Parliament, a body that gives voice to the citizens of the EU, ensuring that the collective public interest shapes the environmental narrative. Alongside the Parliament, the Council of the European Union brings to the table the perspectives of individual member states, ensuring that the local realities of each country are woven into the EU's green tapestry (European Commission, 2023; European Parliament, 2023).

The EU has unveiled a variety of plans, some of which are especially pertinent to the intersection between Industry 4.0 and SMEs. The Circular Economy Action Plan, for instance, is not merely a policy document but a call to action for businesses to embrace a lifecycle

approach to resource use (Ghisellini et al., 2016). It nudges SMEs towards innovative digital solutions that can lead to greater resource efficiency—a key aspect of Industry 4.0. The Industrial Strategy for Europe is another strand that seeks to bolster the competitiveness of the EU's industrial base, ensuring that SMEs are not left behind in the digital leap forward while aligning with the EU's green aspirations. The Digital Europe Program, with its focus on digital transformation, is a catalyst for SMEs to harness digital tools and technologies, fostering growth that is both innovative and environmentally conscious (European Commission, 2021).

The EU climate law initiative weaves yet another crucial strand into the EU's green strategy (Climate Action, 2023). With its ambitious goal to slash greenhouse gas emissions by 55% come 2030, it sets a clear and challenging course for SMEs. These businesses are encouraged to integrate green technologies and practices into their operations—many of which are integral components of Industry 4.0—to meet these stringent targets. This initiative is not just about meeting numbers; it is about transforming the very way SMEs operate, making them pioneers in a green industrial revolution (European Commission, 2023).

These strategies are not standalone efforts but are interconnected in the EU's grand vision of a sustainable, digital future. By fostering an ecosystem that encourages innovation and sustainability, the EU is ensuring that its industries, especially SMEs, are not just surviving but thriving in a world that is rapidly embracing a digital and green future.

Building on the introduction's foundation, the objectives of this systematic literature review are succinctly articulated as follows:

Objective 1: Assessing Policy Directions in Reviewed Articles

This objective is centered on examining the policy directions discussed in the literature. It seeks to summarize the key points of the EU's strategy framework for green initiatives and the adoption of Industry 4.0 technologies by SMEs. The focus will be on identifying the key policy orientations and how they are designed to support SMEs in the transition towards a greener and more technologically integrated future.

Objective 2: Exploring Stakeholder Engagement in Policy Development

The second objective delves into the nature and extent of stakeholder engagement as presented in the academic articles. It seeks to understand the roles various stakeholders play in shaping the policies that drive the adoption of Industry 4.0 by SMEs. This includes looking at how stakeholders' contributions and collaborations are reflected in the policy-making process and the impact of such engagements on policy outcomes.

Methodology

The methodology of this systematic literature review was meticulously designed to ensure a comprehensive and rigorous analysis of the European Union's policy orientation and stakeholder engagement in green initiatives for Industry 4.0 adoption in SMEs. The search strategy and selection process were underpinned by a combination of technical evidence collection, stakeholder engagement analysis, and policy impact assessment.

Search Strategy and Article Selection

The initial search was conducted using a combination of keywords on Scopus and Web of Science databases to ensure a wide coverage of the relevant literature. The keywords used were strategically chosen to capture the essence of the EU's green initiatives in Industry 4.0 for SMEs, policy orientation, and stakeholder engagement. The search was limited to articles published between 2020 and 2023 to focus on the most recent initiatives post-COVID-19 as pandemic have had a significant impact on the initiatives encouraging implementation of Industry 4.0 technologies in businesses (Teixeira & Tavares-Lehmann, 2022). The keywords included combinations of "EU," "Green Initiatives," "Industry 4.0," "SMEs," "Policy," "Sustainability," "Digital Transformation," "Policy Framework," "Regulatory Landscape," and "Stakeholder Engagement."

The initial search yielded approximately 300 articles. These were narrowed down to 18 relevant articles through a rigorous screening process. The inclusion criteria focused on articles that specifically addressed the EU's policies and green initiatives in the context of Industry 4.0 and SMEs. The exclusion criteria removed articles that did not directly relate to the EU's policy framework or stakeholder engagement.

There is a clear research gap highlighted by the noticeable scarcity of publications that particularly address SMEs in the context of EU green initiatives and Industry 4.0 adoption. The limited focus on SMEs is particularly striking given their pivotal role in the European economy and their unique challenges and opportunities in the digital transformation era. The predominance of literature on broader business contexts suggests that while the overarching policies of the EU are well-documented, there is a pressing need for a more granular analysis that considers the specificities of SMEs. This review, therefore, not only seeks to synthesize the existing body of knowledge but also to highlight this gap, advocating for a more targeted research agenda that can inform policy formulation and stakeholder engagement strategies tailored to the needs of SMEs. The findings of this review are expected to contribute significantly to the academic discourse and provide a foundation for future empirical studies focused on this critical sector.

Data Extraction and Synthesis

Data extraction was tailored to gather information relevant to the EU's policy directions and stakeholder engagement from the selected articles. The synthesis process involved summarizing the key points related to policy orientation and the roles of various stakeholders as discussed in the literature. This step was crucial in identifying the alignment of policy initiatives with the needs of SMEs and the extent of stakeholder influence on policy outcomes.

Policy Orientation and Stakeholder Engagement Analysis

The analysis focused on the policy orientations and engagement of stakeholders outlined in the literature. The aim was to understand the strategic direction of the EU's policies and the

dynamics of stakeholder involvement in shaping these policies. This included a review of the discussions on policy frameworks, strategies, and the engagement of SMEs and other stakeholders in the policy-making process.

Findings and Discussion

The European Union has been at the forefront of integrating green initiatives with the technological revolution known as Industry 4.0. This integration is not only a strategic move towards sustainability but also a response to the global competitive pressures and the need for technological sovereignty (Tang et al., 2022). The EU's policy orientation has been shaped by several key themes and issues, which will be discussed in detail, drawing on the findings from reviewed articles.

Teixeira and Tavares-Lehmann (2022) attempted to categorize the several EU policies that are being enhanced and put into effect to promote Industry 4.0 as follows:

European Platform of National Initiatives: Created in 2017, this platform brings together national initiatives that aim to stimulate digitalization. It promotes coordination, financial support, and the sharing of experiences, research, and best practices.

European Stakeholder Forum: Established to promote contact between different initiatives, this forum focuses on financial support, regulation, coordination, and creating opportunities for new sectoral investments.

European structural and investment funds: The European Commission encourages member countries to frame their digitalization policies within the opportunities provided by these funds.

Public-private partnerships and digital industrial platforms: The EU strategy emphasizes creating leadership through large-scale partnerships and platforms to drive digital transformation in industries.

However, based on articles that are researched in this study, this classification does not cover all the policy orientations that were investigated in terms of EU policies towards the adoption of Industry 4.0 technologies in SMEs. In this regard, it becomes apparent that the complexities of EU initiatives extend beyond the categories proposed by Teixeira and Tavares-Lehmann (2022). As our comprehensive review reveals, there are additional dimensions and nuanced approaches embedded within the EU's strategic framework for fostering Industry 4.0 integration.

To provide an example, we have summarized a portion of our findings into Table 1, which highlights particular policy orientations found in a number of articles. It is noteworthy that Table 1 provides an instructive example that captures the variety of the EU's initiatives to promote Industry 4.0 in the context of SMEs. It does not, however, represent all of the articles that have been evaluated. The next sections provide a complete overview of our findings, while the table provides a snapshot of the range of approaches recorded in our study.

The EU policies' orientation and stakeholder participation were categorized as follows, based on the policies that are featured in the research's evaluated publications.

Policy Orientations

1. Modernization and De-carbonization

This orientation of policies is in line with the EU Climate Law initiative. The EU's commitment to modernization and de-carbonization of energy-intensive industries is a central theme in its policy orientation. The focus on breakthrough technologies, such as zero-carbon steel making, reflects the EU's dedication to advancing manufacturing with sustainability in mind. Despite challenges, such as business corruption (Chatzistamoulou, 2023), the EU strives to lead global efforts in de-carbonization and digitalization, aiming to become the first carbon-neutral continent by 2050. The twin transitions of digitalization and sustainability are core European concepts, driving advancements in manufacturing to support these transitions (Malik, 2023).

Table 1: Summary of findings

Article Title	Author(s) & Year	Research Field	Policy Orientation	Stakeholders
Industry 4.0 as an enabler of circular economy practices: Evidence from European SMEs	Findik et al., 2023	Investigate the link between circular economy practices and I4.0 technologies	Twin Transition: Digital and Green transition EU should prioritize I 4.0 for SMEs to improve Their CE practices	EU policy makers are considered as the main stakeholder in this research
Creating Value with Environmental, Social, Governance (ESG) in Irish Manufacturing SMEs': A Focus on Disclosure of Climate Change Risks and Opportunities	Cronin and Doyle-Kent, 2022	Evolving regulations and increasing pressure from governments and consumers on SMEs to move towards sustainability	De-carbonization: Policy direction towards increased transparency and accountability in environmental impact reporting	SMEs and owners
Going beyond waste reduction: Exploring tools and methods for circular economy adoption in small-medium enterprises	Mickey Howard et al., 2022	Explores tools and methods to improve SMEs' chances of adopting CE	Circular Economy**:** Waste reduction and value creation through resource optimization	SMEs and UK government Engagement approach: participatory
EU technology-specific industrial policy. The case of 5G and 6G	Maria Alessandra Rossi, 2023	Assesses EU policies and initiatives related to 5G and 6G, focusing on demand and adoption patterns.	Analysis of the EU's policy priorities in the context of 5G and 6G technologies: Digital Sovereignty	Not specifically mentioned Implies: Importance of governance and policy coordination
The circular economy implementation at the European Union level. Past, present and future	De Pascale et al., 2023	EU policy framework that encourages sustainable economic growth, innovation, and employment.	EU's policy direction and priorities in relation to sustainability and digital transformation goals. Circular Economy/Sustainability	Three main categories of stakeholders involved in CE implementation: policymakers, businesses, and other society stakeholders

The future of the technology-based manufacturing in the European Union	Awadesh Kumar Mallik, 2023	Modernizing and decarbonizing energy-intensive industries to support its climate neutrality goal	Modernization and De-carbonization: For example: zero-carbon steel making	Involving stakeholders through co-creation, public-private partnerships, and consultative events (policymakers, academia, civil society)
5G roll-out failures addressed by innovation policies in the EU	Blind and Niebel, 2022	Focuses on addressing 5G rollout 'failures' and policy measures in the EU.	Digital Sovereignty resulting in secure and diverse supply chain can be referred as digital economy	Public-private sector partnership.
Advances towards circular economy policies in the EU: The new Eco-design regulation of enterprise servers	Talens Peiró et al., 2020	Analyzes the EU's policy direction and priorities in relation to sustainability and digital transformation goals.	Implementing CE measures within product policies of EU for energy efficiency	Main: Manufacturers, independent IT service providers, end-of-life operators, Others: European Standardization Organizations (ESOs), member states
Assessing the level of digital maturity in the Three Seas Initiative countries	Brodny and Tutak, 2023	EU's policies and initiatives aimed at fostering digital and green transitions, within the Three Seas Initiative	Digital maturity to create competitive advantage/ Digital Economy	Governments, enterprises, and possibly other entities such as research institutions

Source: Author's own work

2. Addressing Challenges in Adopting Digitalization and Industry 4.0

EU industries grapple with challenges arising from natural disasters, the COVID-19 pandemic, and a reevaluation of offshoring practices. The integration of IT systems in manufacturing, concerns about disruptions and security breaches, and efforts to create a single digital market underscore the EU's commitment to overcoming challenges associated with adopting Industry 4.0 (Peiró et al., 2020). New legislations, strategies, and services are being formulated to ensure product and data safety in the face of evolving threats. Moreover, EU's policies try to address barriers that intervene effective implementation of technologies such as ack of awareness and information about green practices, as well as cultural and behavioral factors (Lam-González et al., 2023).

3. Circular Economy and Sustainability

The EU's circular economy policy is anchored in achieving zero waste, with a focus on recycling, remanufacturing, and the use of renewable energies. This approach not only reduces dependence on foreign resources but also aligns with sustainability goals. The integration of digital technologies is anticipated to foster new business models, enhance productivity, and contribute to the broader de-carbonization of the economy. Therefore, CE related policies are

reflected as one of the main orientations in EU policies towards adopting Industry 4.0 technologies in SMEs (Howard et al., 2022).

4. Digital Sovereignty and Innovation

The concept of digital sovereignty is prominent in EU policies, particularly in relation to securing a diverse and secure supply chain (Blind & Niebel, 2022). Articles within the research highlight digital sovereignty as a critical aspect, referring to it as a component of the digital economy. This orientation emphasizes the need for the EU to maintain control and security over its digital infrastructure, thereby fostering innovation and ensuring a resilient and competitive digital landscape.

Stakeholder Engagement

Stakeholder engagement is a critical aspect of shaping policies that drive the adoption of Industry 4.0, especially when considering the unique landscape of small and medium-sized enterprises (SMEs). Academic literature reveals a multifaceted involvement of stakeholders in the policy-making process, emphasizing collaboration and contributions from various actors (Blind & Niebel, 2022; Peiró et al., 2020; Howard et al., 2022).

1. Roles of Stakeholders

SMEs themselves are pivotal stakeholders in the development of policies (Cronin & Doyle-Kent, 2022). Research by Cronin and Doyle-Kent (2022) highlights the active role SMEs play in providing insights into their specific needs, challenges, and aspirations regarding Industry 4.0 adoption (Cronin & Doyle-Kent, 2022).

Government bodies are instrumental in policy development. The study by Journeault et al. (2021) underscores the importance of regulatory bodies in creating an enabling environment for SMEs to embrace Industry 4.0 technologies (Journeault et al., 2021).

Industry associations and advocacy groups contribute significantly. The work of Brodny and Tutak (2023) demonstrates how collaborative efforts with industry associations influence policy outcomes, ensuring alignment with SME interests (Brodny & Tutak, 2023).

2. Contributions and Collaborations

Stakeholder engagement involves active collaborations between SMEs, governmental bodies, and industry players. The previous studies illustrate successful policy outcomes resulting from collaborative initiatives that incorporate diverse stakeholder inputs (De Pascale et al., 2023; Peiró et al., 2020).

Public-private partnerships emerge as a prevalent collaboration model. Howard et al., (2022) showcases successful engagements between SMEs and private entities, contributing to the formulation of policies that address technological challenges and foster innovation (Howard et al., 2022)

3. Impact on Policy Outcomes

Stakeholder engagement significantly impacts policy outcomes. The findings demonstrate that policies shaped through extensive stakeholder involvement are more likely to be effective, sustainable, and well-aligned with the needs of SMEs (Hollebeek et al., 2022; Brodny & Tutak, 2023).

The level of engagement and inclusivity in the policy-making process directly influences the successful implementation of Industry 4.0 initiatives in SMEs. This is evidenced in the study by Cronin and Doyle-Kent, (2022), emphasizing the need for ongoing collaboration to address evolving challenges (Cronin & Doyle-Kent, 2022).

Conclusion

In conclusion, this research set out to achieve two key objectives: firstly, to assess the policy directions discussed in the literature, and secondly, to explore stakeholder engagement in the development of policies driving the adoption of Industry 4.0 by SMEs. The findings reveal a dynamic and comprehensive policy landscape within the European Union, where the integration of green initiatives with Industry 4.0 represents a strategic response to global competitive pressures and a commitment to technological sovereignty. The categorization of policy orientations, including modernization and de-carbonization, addressing challenges in adopting digitalization, circular economy and sustainability, and digital sovereignty and innovation, provides a nuanced understanding of the multifaceted approaches employed by the EU. Notably, the identified policy orientations extend beyond existing classifications, emphasizing the intricacies of EU initiatives for fostering Industry 4.0 integration.

The stakeholder engagement aspect underscores the pivotal roles of SMEs, government bodies, industry associations, and private entities in shaping policies. Collaboration and contributions from these diverse actors are evident in successful policy outcomes that align with SME interests. The impact of stakeholder engagement is pivotal, influencing the effectiveness, sustainability, and alignment of policies with the needs of SMEs. The research contributes to the understanding of how EU policies and stakeholder engagement collectively drive the adoption of Industry 4.0 in SMEs, paving the way for a greener, technologically integrated future with a resilient and competitive digital landscape.

References

Blind, K., & Niebel, C. (2022). 5G roll-out failures addressed by innovation policies in the EU. *Technological Forecasting and Social Change,* 180, 121673.

Brodny, J., & Tutak, M. (2023). Assessing the level of digital maturity in the Three Seas Initiative countries. *Technological Forecasting and Social Change*, 190, 122462.

Büchi, G., Cugno, M., & Castagnoli, R. (2020). Smart factory performance and Industry 4.0. *Technological forecasting and social change*, 150, 119790.

Chatzistamoulou, N. (2023). Is digital transformation the Deus ex Machina towards sustainability transition of the European SMEs?. *Ecological Economics*, 206, 107739.

Climate Action (2023) The European Cimate Law from https://climate.ec.europa.eu/eu-action/european-climate-law_en#:~:text=The%20European%20Climate%20Law%20writes,2030%2C%20compared%20to%201990%20levels. (Downloaded on October 12, 2023)

Cronin, M., & Doyle-Kent, M. (2022). Creating Value with Environmental, Social, Governance (ESG) in Irish Manufacturing SMEs': A Focus on Disclosure of Climate Change Risks and Opportunities. *IFAC-PapersOnLine*, 55(39), 48-53.

De Pascale, A., Di Vita, G., Giannetto, C., Ioppolo, G., Lanfranchi, M., Limosani, M., & Szopik-Depczyńska, K. (2023). The circular economy implementation at the European Union level. Past, present and future. *Journal of Cleaner Production*, 138658.

Ehlers, M. H., Finger, R., El Benni, N., Gocht, A., Sørensen, C. A. G., Gusset, M., Huber, R. (2022). Scenarios for European agricultural policymaking in the era of digitalization. *Agricultural Systems*, 196, 103318.

European Commission. (2021). A New Industrial Strategy for Europe. Retrieved from https://ec.europa.eu/info/sites/default/files/communication-eu-industrial-strategy-march-2020_en.pdf (Downloaded on October 14, 2023)

European Commission. (2023). The European Green Deal. Retrieved from https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (Downloaded on October 10, 2023)

European Parliament. (2023). Legislative Powers. Retrieved from https://www.europarl.europa.eu/about-parliament/en/powers-and-procedures/legislative-powers (Downloaded on October 10, 2023)

Findik, D., Tirgil, A., & Özbuğday, F. C. (2023). Industry 4.0 as an enabler of circular economy practices: Evidence from European SMEs. *Journal of Cleaner Production*, 410, 137281.

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner production,* 114, 11-32.

Howard, M., Yan, X., Mustafee, N., Charnley, F., Böhm, S., & Pascucci, S. (2022). Going beyond waste reduction: Exploring tools and methods for circular economy adoption in small-medium enterprises. *Resources, Conservation and Recycling*, 182, 106345.

Journeault, M., Perron, A., & Vallières, L. (2021). The collaborative roles of stakeholders in supporting the adoption of sustainability in SMEs. *Journal of environmental management*, 287, 112349.

Klein, V. B., & Todesco, J. L. (2021). COVID-19 crisis and SMEs responses: The role of digital transformation. *Knowledge and Process Management*, 28(2), 117-133.

Lam-González, Y. E., León, C. J., de León, J., & Suárez-Rojas, C. (2023). Mooring in the green room. Sailors' preferences and willingness to pay for green policies in marinas. *Journal of Cleaner Production*, 419, 138227.

Liu, Q., Trevisan, A. H., Yang, M., & Mascarenhas, J. (2022). A framework of digital technologies for the circular economy: Digital functions and mechanisms. *Business Strategy and the Environment*, 31(5), 2171-2192.

Mallik, A. K. (2023). The future of the technology-based manufacturing in the European Union. *Results in Engineering*, 19, 101356.

Mourtzis, D., Angelopoulos, J., & Panopoulos, N. (2022). A Literature Review of the Challenges and Opportunities of the Transition from Industry 4.0 to Society 5.0. *Energies*, 15(17), 6276.

Paiho, S., Wessberg, N., Dubovik, M., Lavikka, R., & Naumer, S. (2023). Twin transition in the built environment–Policy mechanisms, technologies and market views from a cold climate perspective. *Sustainable Cities and Society*, 98, 104870.

Peiró, L. T., Polverini, D., Ardente, F., & Mathieux, F. (2020). Advances towards circular economy policies in the EU: The new Ecodesign regulation of enterprise servers. *Resources, Conservation and Recycling*, 154, 104426.

Rossi, M. A. (2023). EU technology-specific industrial policy. The case of 5G and 6G. *Telecommunications Policy*, 102639.

Tang, Y. M., Chau, K. Y., Fatima, A., & Waqas, M. (2022). Industry 4.0 technology and circular economy practices: business management strategies for environmental sustainability. *Environmental Science and Pollution Research*, 29(33), 49752-49769.

Teixeira, J. E., & Tavares-Lehmann, A. T. C. (2022). Industry 4.0 in the European union: Policies and national strategies. *Technological Forecasting and Social Change*, 180, 121664.

Hollebeek, L. D., Urbonavicius, S., Sigurdsson, V., Clark, M. K., Parts, O., & Rather, R. A. (2022). Stakeholder engagement and business model innovation value. *The Service Industries Journal*, 42(1-2), 42-5