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Article

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Scientific Papers of the University of Pardubice, Series D: Faculty of Economics and Administration

Provided in Cooperation with:

Faculty of Economics and Administration, University of Pardubice

Suggested Citation: Majid, Sara (2024) : Digitalisation as a tool to enhance eco-efficiency measures: A systematic literature review, Scientific Papers of the University of Pardubice, Series D: Faculty of Economics and Administration, ISSN 1804-8048, University of Pardubice, Pardubice, Vol. 32, Iss. 2, pp. 1-18,
<https://doi.org/10.46585/sp32022086>

This Version is available at:

<https://hdl.handle.net/10419/334839>

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Digitalisation as a Tool to Enhance Eco-efficiency Measures: A Systematic Literature Review

Scientific Papers of the University of Pardubice, Series D: Faculty of Economics and Administration 2024, 32(2), 2086.
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DOI: 10.46585/sp32022086
editorial.upce.cz/SciPap

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Abstract

Digitalisation has become a key process for companies to improve their sustainability, yet a clear overview of the challenges and achievements within European Small and Medium-sized Enterprises (SMEs) regarding digitalisation is still lacking in the literature, making it difficult to identify research gaps or quantify the impact digitalisation has on the European SME market. This paper examines digitalisation as an enabler for European SMEs to improve their environmental sustainability and specifically considers the implementation of eco-efficiency measures such as waste reduction and waste management and thus confirms whether digitalisation can enhance eco-efficiency measures or not within European SMEs. The study is based on a bibliometric analysis followed by a systematic literature review. In particular, it first synthesizes the existing state-of-the-art research and summarizes theoretical frameworks, to explain main themes and gaps in the literature published from the year 2020. Selected articles focusing on European SMEs and digitalisation practices in the context of eco-efficiency are revised in detail. This review identifies common challenges and opportunities associated with digitalisation in the context of European SMEs while offering pathways to address the research gaps.

Keywords

Digitalisation eco-efficiency, Small and Medium Enterprises (SMEs), Environmental sustainability, Waste reduction, Energy efficiency, Europe

JEL Classification

Q56, L86, O32, L26, M15, C80

Introduction

There is a surge of interest in eco-efficiency actions among businesses of all sizes (Tripathy et al., 2024). Developed in 1991 by the World Council for Sustainable Business Development, the concept of eco-efficiency is commonly defined as the ratio between environmental impact and economic cost or value (Huppes & Ishikawa 2005). In practical terms, eco-efficiency measures are processes undertaken by any business that refers to dealing in products and services, strategies and systems that positively impact the environment while creating value (Côté et al., 2006; Yin & Liu, 2023). One of the key technological developments that can aid these businesses in implementing eco-efficiency actions is digitalisation. According to the United Nations 2030 Agenda, digital technology can enhance sustainability and ensure that firms comply with the Sustainable Development Goals (SDGs) that are closely aligned with eco-efficiency (Camodeca & Almici, 2021) such as SDG 11, 12, 13. This especially applies to SMEs, where digital transformation has been shown as a crucial process and strategy for their growth and survival (Kim & Ha, 2023). For example, SMEs would need to develop carefully planned strategies for reducing landfill waste and proper waste management (SDG 11) (Sala-Garrido et al., 2024) as well as adopting clean technologies (SDG 12) (Özbuğday et al., 2020) and implementing green practices to reduce carbon emissions (SDG 13) (Kovalov 2024). On top of that, studies on particular digitalisation strategies for implementing eco-efficiency in particular industries is already available in the literature (Beier et al., 2020; Lichtenthaler, 2021; Szabo et al., 2020, Cawley, 2019). For example, both micro and small companies can implement straightforward measures such as using digital processing to optimize waste reduction and water conservation (Torky & Hassanein, 2020) or more dedicated software-based optimization tools such as described in (Kong et al., 2011). In addition, (Kowal et al., 2024; Borcoşi et al., 2023; Radicic 2023; Ghobakhloo et al., 2021) found that digitalisation and digital tools increase the capacity of companies to innovate and grow while providing new benefits to the firm. Other existing studies provide insightful perspectives on a wide range of digital applications (Sugiyama et al., 2017; Schneider, 2019; Rosário & Dias, 2022).

Yet despite the aforementioned positive correlation between eco-efficiency actions and digitalisation, businesses also face numerous challenges during digital transformation (Bucci et al., 2019, Chen et al., 2022). For example,

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many SMEs struggle to move from digital concept to actual implementation (Radicic & Pugh, 2017; Li et al., 2017; Scutto et al., 2021) which can be attributed in part to the lack of organisational capabilities and awareness necessary for implementing such systems (Scutto et al., 2021; Radicic & Petković, 2023) which is why such implementations are often perceived as too complicated to achieve eco-efficiency (Fernando & Evans 2016). These challenges are also revealed in specific use cases regarding the effect of digitalisation on eco-efficiency measures and consequently business performance within the context of SMEs (Rodríguez-Espíndola et al., 2022). For example, (Wang et al., 2021) explored how recent developments in AI affect business processes and found that SMEs are affected by external and internal factors in navigating the AI landscape while (Gangwar, 2018) found that SMEs are not ready for complex scenarios which could hinder their normal operations. Finally, despite the wealth of available prior studies, a critical assessment of the characteristics of digital technologies that underpin this intervention is still lacking (El Hilali et al., 2020). The literature also lacks a thorough exploration of practical implementation instead of theoretical benefits and conceptual frameworks.

A better understanding of digitalisation characteristics is crucial for developing eco-efficiency measures relevant to SMEs (Lorenz et al., 2020; Rosário & Dias, 2022). Therefore, this review identifies and critically evaluates characteristics of digitalisation that support its implementation in SMEs, as well as analyse how effective these characteristics are, using empirical, non-conceptual papers. This review is not only a confirmation of existing knowledge but also provides a significant contribution to progress in this area by guiding future research efforts.

The study contributes in several ways to the existing literature on digitalisation and eco-efficiency. A comprehensive bibliometric analysis is performed whose results provide a comprehensive picture of digitalisation's evolution and its relation to eco-efficiency measures, such as waste management. In addition, it helps to identify the trends in publications per year, including the total number of publications, countries, and keyword search terms. A bibliographic coupling of journals, authors, countries, and keywords is also highlighted. Next, the study conducts a systematic literature analysis according to PRISMA-2020 guidelines. A total of 29 relevant studies are considered in the analysis (the 1001 papers are narrowed down to only papers dealing with digitalisation efforts for eco-efficiency within European SMEs). Special emphasis is placed on the determinants and impacts of digitalisation and eco-efficiency on waste management. This study can therefore serve as a guide for improving and implementing eco-efficiency measures in European SMEs and as a reference for more sustainable and efficient practices. On top of that, this analysis also identifies research gaps and limitations. Possible solutions to address these gaps and provide directions for future research are provided in this work. As such, this study will clarify whether digitalisation can enhance eco-efficiency measures or not within European SMEs and which directions future research should take.

Literature review

Since the focus of this study is eco-efficiency and digitalisation, this section provides a few important definitions of eco-efficiency that are relevant to the topic at hand. The purpose of this section is to examine eco-efficiency measures and understanding the connection between eco-efficiency measures and digitalisation in SMEs, which is supported by previous researches (Bharadwaj et al., 2013; Mithas et al., 2013; Becker & Schmid, 2020). Lastly in this section the studies were explored that focus on digitalisation's ability to transform business functions within European SMEs.

The concept of eco-efficiency measures

Since the concept of eco-efficiency was proposed in 1991 by the World Council for Sustainable Business Development, eco-efficiency has become an increasingly popular research topic (Cui et al., 2022, Luo et al., 2021; Sun & Wang, 2021; Kounetas et al., 2021). Eco-efficiency means creating more value for businesses/institutions while minimising the consequent environmental impact (Hernández Pardo et al., 2012). In particular, eco-efficiency measures are processes undertaken by any business such as dealing in products and services, strategies, systems, and measures, that positively impact the environment while creating value (Vásquez et al., 2019). Such can be applied within many different industries institutions and regions, and hence, numerous scholarly studies have defined eco-efficiency according to the applications or the scholars' research fields, which are outlined in Table 1.

In particular, eco-efficiency measures can range from cutting-edge technologies like blockchain innovation as well as simple yet impactful steps like reducing water consumption or saving electricity. When it comes to SMEs however, these measures need to be aligned with their ecological motive but not at the cost of monetary decline or loss of profit (Passetti & Tenucci, 2016). Nevertheless, not only have previous studies demonstrated the significance of eco-efficiency measures in achieving sustainable development (Jové-Llopis & Segarra-Blasco, 2018; Changwichan et al., 2018), but also confirmed that eco-efficiency measures could create a "win-win" situation for every stakeholder involved in this process. For example, measures like saving energy, minimising waste and saving materials (Jové-Llopis & Segarra-Blasco, 2018).

Table 1. List of eco-efficiency definitions including the years the definitions were proposed and by whom.

Year	Source	Definitions
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WBCSD 2000	World Business Council for Sustainable Development	Achieving more value from lower inputs of material and energy, with reduced emissions
OECD 1998	Organization for Economic Cooperation and Development	Efficiency with which ecological resources are used to meet human needs
2000	Lehni	Creating more value with less impact
2005	Schütz and Welfens	to "get more from less"
2005	Huppés & Ishikawa	Reducing the environmental impact of the product and increasing its economic value
2015	Rashidi & Farzipoor Saen	Sustainability can be evaluated by the eco-efficiency.

Kind of eco-efficiency measures

All aspects of business must be eco-efficient to reduce the impact on the environment (Lueddeckens, 2022). Integrating such measures into an organization's environmental management system is an important component of achieving eco-efficiency (Rashidi & Farzipoor Saen, 2015). The measures can include 1) reducing water, energy, and materials 2) reducing waste and reducing carbon emissions 3) resource optimization, 4) designing more sustainable products 5) recycling and usability. In this paper, waste reduction and management will be a primary focus. Due to rapid industrialization and globalization, a plethora of waste issues have been produced, and it is a very alarming situation for nature and human life. The European Union produced approximately 2.5 billion tons of waste in 2012, and about 45.3 thousand firms are reported to be actively engaged in waste management practices (Eurostat). According to UNEP (2011), annual solid waste collected was close to an alarming 11.2 billion tons worldwide. One of the primary causes of this waste production is the population rise (Glavič, 2021). While technological advancements and innovation (might have improved the overall quality of life, they have also caused overconsumption and excessive waste production (Sproedt et al., 2015). As such, waste management is considered one of the most crucial challenges for concerned government authorities and businesses, particularly for big cities (Bugge et al., 2019).

Efficiently preventing or minimising waste is the most straightforward activity in managing waste and being eco-efficient. Waste management within most European regions is heavily legislated on a national level (Directive 2008). Despite these regulations, other societal actors must also reduce waste, like households and SMEs since managing waste is a collective effort, i.e., one person or one company will not achieve a substantial impact; instead, multiple organizations and governments' cooperation is necessary (Oh & Hettiarachchi, 2020). 94 percent of Europeans consider environmental protection an essential aspect of their lives, it is still not a sufficient basis for transitioning towards a highly sustainable economy unless the economy's agents actively contribute towards it.

Eco-efficiency measures and digitalisation in SMEs

A crucial tool to implement eco-efficiency actions such as waste reduction and management, is digitalisation. Digitalisation refers to adopting digital technologies and communications to transform business functions and models to provide more value to businesses as well as create new opportunities (Bharadwaj et al., 2013; Mithas et al., 2013; Becker & Schmid, 2020).

It enables organizations to reach a bigger and wider market while creating innovation and growth, thus providing potential competitive advantages (Bouwman et al., 2019). Indeed, digitalisation has transformed business operations across all sectors and is considered a game changer in transforming economies, market trends, and business operations (Seele & Lock, 2017; Kottmeyer, 2021). In a post-pandemic world, digitalisation is even more significant for all business sectors, as it has become a global way of life (Ben-Zvi & Luftman, 2022).

The importance of digitalisation is also apparent in the case of SMEs (Barker et al., 2024). Since SMEs within the European Union represent 99% of all businesses (with 200 million in employment), they are considered to be the backbone of the European economy. As a result, digitalisation, through SMEs, is clearly an important driver of social and economic changes within the European Union especially when taking into account that SMEs have the potential to drive innovation when it comes to achieving sustainable business solutions (Parrilli et al., 2023; Majid et al., 2023). Indeed, empirical studies have shown that digital transformation can lead to sustainable competitive advantages through boundary-spanning activities (Xue & Wang, 2023). This is also true for eco-efficiency, for which several researchers found that digitalisation, along with financial development, can significantly influence eco-efficiency and play a crucial role in reducing energy consumption and pollution (Yang & Liang, 2023; Mei et al., 2023; Han, 2024). For example, energy conservation and emissions reduction decisions are made more accurately when these factors are present. Some researchers are concerned that digital technology might have negative consequences such as regulatory arbitrage (Kottmeyer, 2021) being harmful to the biosphere (Mura & Donath, 2023). However, extensive research has shown that digitalisation can significantly enhance eco-efficiency by optimising resource use and enabling more precise monitoring of environmental impacts, clearly demonstrating that the potential costs outweigh the benefits. This is certainly true for SMEs, as SMEs can streamline their operations, reduce waste, and control pollution more efficiently using digital technologies such as IoT, big data analytics, and AI (Patwa et al., 2021). Additionally, digital tools facilitate and improve overall usability, leading to a

more sustainable business model (Cenamor et al., 2019). Their profitability can also increase as a result. Furthermore, these technologies can assist SMEs in better tracking their carbon footprint and making more informed decisions about their innovation efforts.

However, despite all these benefits, it can be challenging for SMEs to keep up with a complex process on so many fronts, covering digital technologies on the one hand and updating their offerings to maintain a competitive advantage beyond the required sustainability compliance on the other hand, which means they miss out on creating additional value. Indeed, for any company to stay competitive, proper resources and technology applications are essential, such as sufficient knowledge regarding certain technologies and processes and the human capital to implement and manage these new technologies with the necessary skills and expertise (Onkelinx et al., 2016; Ferreira & Fernandes, 2017). Hence, human capital plays a critical role in digital transformation. Skilled workers are essential for navigating the complexities of digital systems and ensuring their successful integration into existing processes. Without a knowledgeable and adaptable workforce, companies may struggle to fully realize the benefits of digital innovation, which encompasses digital tools such as Information and communication technology (ICT), Artificial intelligence (AI), blockchain, and the techniques they support for digital marketing, e-commerce, big data, advanced data analytics, internet of things (IoT), and so on. All of these help companies optimise operations, expand their reach, make informed decisions, drive their progress, and influence societal transformation (Pappas et al., 2018). While big firms can afford to take advantage of these, SMEs and micro firms are hesitant to opt for digital technologies as they can be complicated, costly, time-consuming, or too risky (Madrid-Guijarro et al., 2016), which is especially true when there is limited financial resources or digital know-how. Indeed, the complexity of technology (Motta et al., 2013) and lack of knowledge, skills, digital standards, and digital human resources are often a deal-breaker in SMEs (Madrid-Guijarro et al., 2016; Indrawati et al., 2020). Aside from these factors, SMEs also struggle to have adequate organizational capacity (such as organizational culture and norms), which are also crucial for any organization to implement technological solutions (Blštáková et al., 2020), as organizational culture is the basis of adaptability and cohesiveness of the organization (Brunetti et al., 2020).

As such, to help SMEs overcome these barriers and provide sufficient resources, a thorough literature study that summarizes and analyses the relation between eco-efficiency actions and digitalisation is needed. This will not only provide SMEs with a general overview of how digitalisation impacted other SMEs and their ecological footprint, but it will also help other scholars identify gaps in the literature that can be addressed later with more research. As such, this paper provides a literature review, which will be detailed in the following sections.

Materials and methods

A systematic literature review is viewed as a reliable approach to investigating a developing field of research (Raihan, 2024) and provides a rigorous evidence-focused answer to the research question (Okoli & Schabram, 2010; Iden & Eikebrokk, 2013). In this section, an overview of the data search strategy and analysis strategy to generate bibliometric data, the collection of existing studies, and the analysis strategies to prepare bibliometric analyses of digitalisation and eco-efficiency measures literature are provided in this section.

Data source and collection

A systematic search was conducted between June and August 2024 using the Scopus database, selected for its comprehensive coverage and status as a leading source of scholarly papers worldwide (Tripathy et al., 2024). The review utilized bibliometric analysis and a Systematic Literature Review (SLR), adhering to the PRISMA-2020 guidelines as outlined by the British Medical Journal (2021) (Moher et al., 2015; Mustapha et al., 2023; Tomaschko et al., 2024) based on four steps including identification of articles, screening, eligibility, and inclusion. This review aims to highlight an overview of current knowledge and identify any gaps in the literature related to digitalisation and eco-efficiency measures taken by SMEs as well as insights into future research. In addition, this paper provides insights into the implementation of digitalisation efforts of European SMEs regarding their ability to drive innovation and transformation via digitalisation, as well as the impact that digitalisation has on making them eco-efficient.

Search strategy

The Scopus database was selected due to its reliability, extensive amount of data, and high-quality content (Zhao et al., 2021; Benita, 2021). Then VOSviewer was used to visualize bibliometric results due to its ability to visualize data and provide an excellent mapping data (Wong 2018; Bukar et al., 2023). For this review VOSviewer provides a comprehensive picture of digitalisation's evolution and its relation to eco-efficiency measures, such as waste management. The search, summarised in Table 2, used keyword combinations e.g., Digitalisation AND European SMEs AND sustainability AND waste within all research disciplines, including the Publication Titles, Keywords, and Abstracts. Although the article search duration did not specify a start date, more than 97 percent of the literature related to the keywords was published in 2020 and later, clearly showing the major impact the Covid pandemic had on the implementation of digitalisation processes. The initial search resulted in 1001 publications. A birds-eye analysis of these publications and observations of the broader conceptual context will be specified in the following section, in addition to a gradual narrowing down to a total of 29 publications relevant to the detailed literature analysis.

Fig. 2. Co-occurrence of the keywords.

Fig. 2 shows the presence and co-occurrence of the keywords. Once again, a lot of research is centered around China, while sustainable development, sustainability, and circular economy are other topics that dominate these fields. However, it is also clear a lot of the other, fewer represented topics center around global warming, carbon emissions, environment and sustainability, and energy, while digitalisation-related topics only show up sporadically in the literature in combination with these keywords. This suggests that much of the research surrounding digitalisation is very much scattered and deals with specific countries, SDGs, green issues or policies, rather than having a more global, general analysis of the topics affecting digitalisation. It can also imply that the field is so diversified, that such a global analysis is extremely difficult if not impossible, and new metrics need to be explored to enable this research.

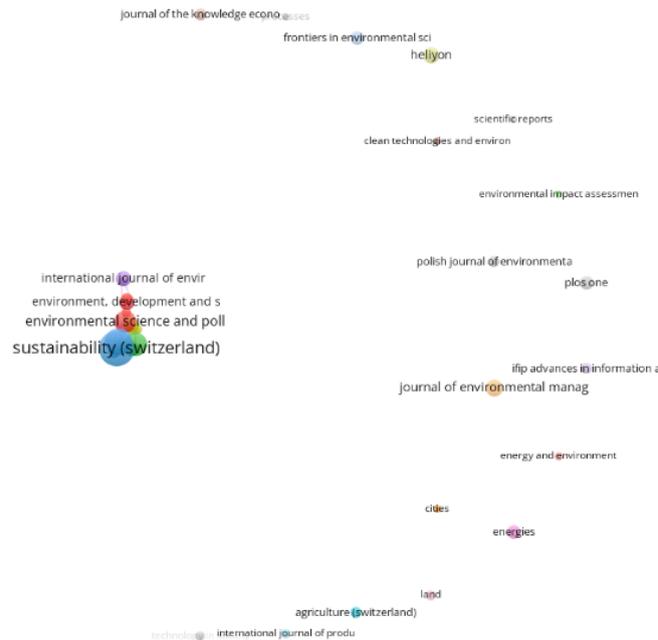


Fig. 3. Journals in which the papers are published, grouped (and linked) based on their co-citations.

Fig. 3 displays the journals in which the papers are published. Clearly, it shows that most of the papers are published in Sustainability (Switzerland), Journal of Cleaner Production, and Environmental Science and Policy. Although Sustainability (Switzerland) is published by MDPI, which has attracted some controversy in recent years (Copiello 2019; Oviedo-García 2021) the fact this journal is overrepresented in this metric indicates that many researchers still prefer disseminating their research findings as Open Access. Another observation is that the relevant articles in these three journals, among a few others, all cite each other, meaning that much of the research in this field is confined to a few journals, while a larger group of other journals only have scattered contributions to the field.

Eco-efficiency, digitalisation and SME(s)

We now narrow down the literature analysis by adding the keyword SME or SMEs in Scopus. This resulted in a total of 319 articles. A similar analysis to the previous sub-section is now performed.

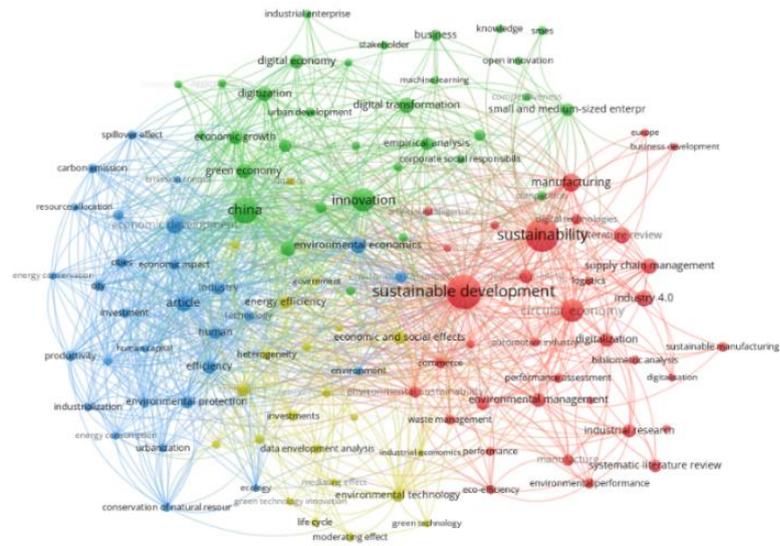


Fig. 4a. Co-occurrence of keywords among 319 articles.

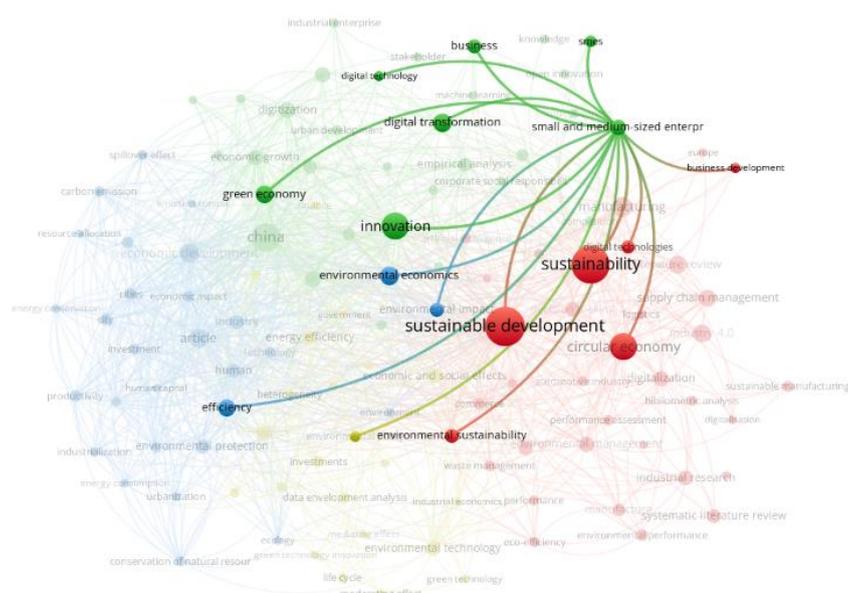


Fig. 4b. Co-occurrence of keywords with SMEs highlighted.

Fig. 4a and Fig. b show how many keywords are present and co-occur. Once again, a lot of research has been conducted on sustainable development, sustainability, and circular economy. There is no doubt that many of the other topics discussed revolve around the digital economy, eco-efficiency, digital transformation, China, and environmental regulation. Nevertheless, it does show that China has a much lower presence on this graph as compared to Fig. 2, which suggests that the field of Chinese SMEs is a topic that deserves or needs more exploration which could be part of a future study dealing with SMEs outside of Europe. Another important observation to note is that when looking for topics related to digitalisation before adding the SME keyword, these topics only appeared infrequently in the literature in combination with these terms. Finally, when looking at Fig. 4b, digitalisation-related topics, although more prominent now amongst the 319 publications, still share little research with SMEs, indicating research in this field is still not at a mature stage and further growth is expected.

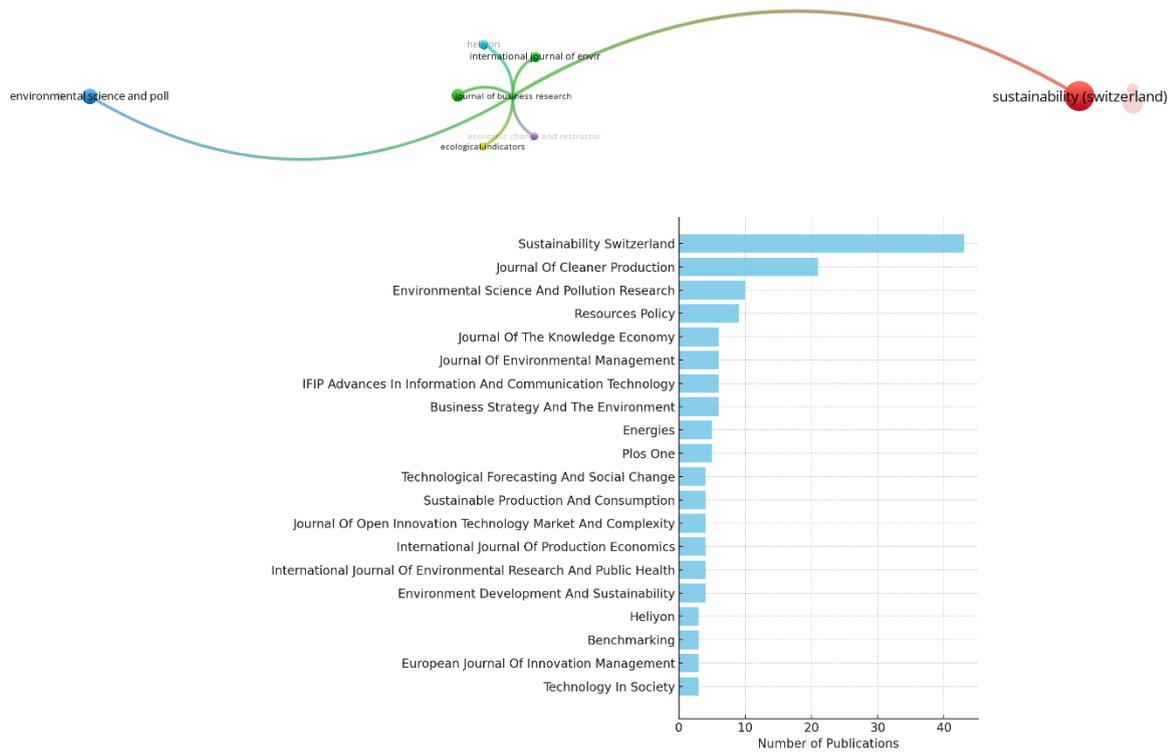


Fig. 5. Journals in which the papers are published and co-citations.

Fig. 5 shows the journals in which the 319 papers were published. It once again shows that most of the papers are published in Sustainability (Switzerland), Journal of Cleaner Production, and Environmental Science and Policy. However, it also shows that the field is a bit more scattered now, while the Journal of Business Research is at the center, meaning it is cited more by the dominant journals (than those journals cite each other) despite having fewer publications on this topic. It suggests that this journal brings together much of the research relevant to eco-efficiency measures and digitalisation in SMEs.

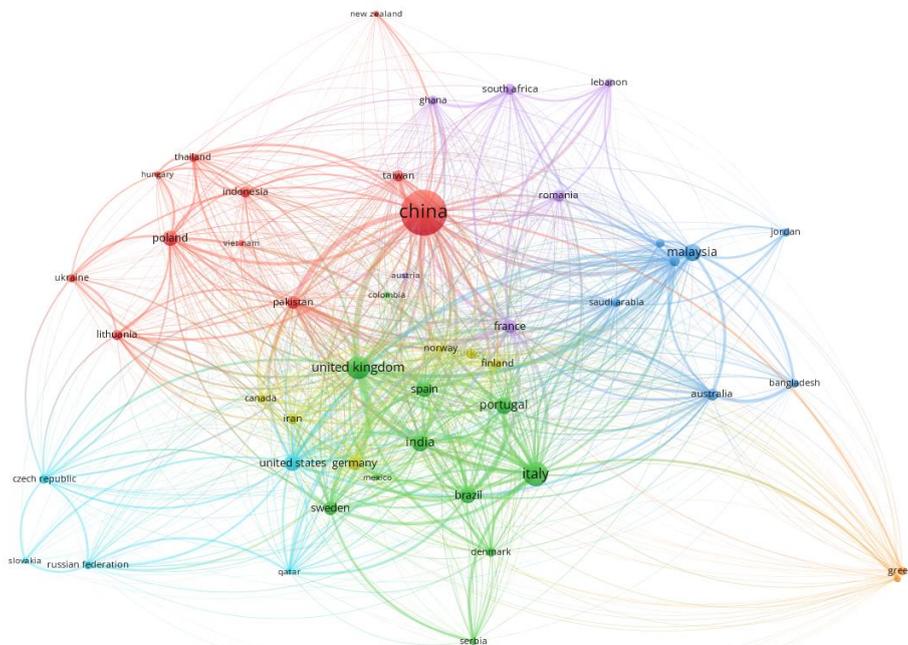


Fig. 6. Bibliographical coupling between countries.

Fig. 6. plots the bibliographical coupling (the number of references they share) between countries – we take as a minimum 2 documents per country. China once again takes center stage in terms of a number of papers, although as mentioned earlier, this research is not focused on domestic SMEs. In Europe, the largest contributors are Italy and the UK, and there is a trend regarding Eastern/Central European countries and Greece and Cyprus where research is clustered along geographical lines. Nevertheless, outside Europe, the research once again is pretty

much scattered, i.e., the authors of these journals tap into research from other countries that are not geographically aligned with theirs.

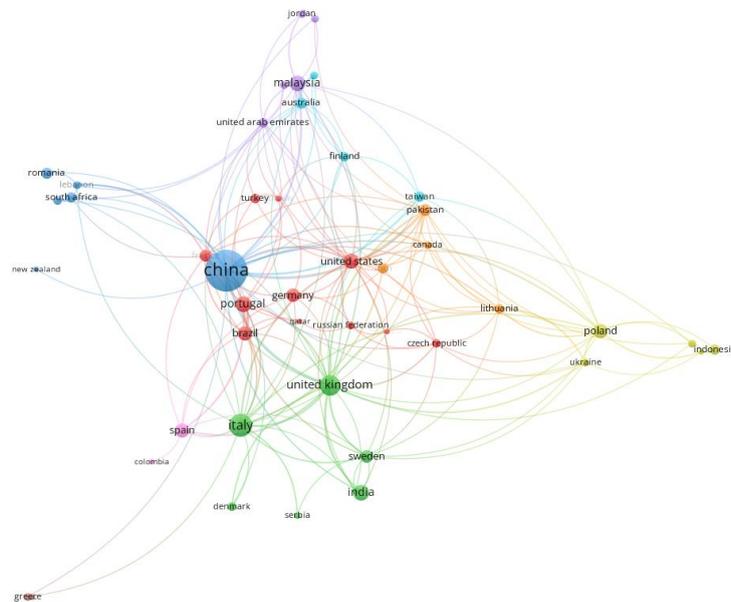


Fig. 7. Co-authorship between countries.

Fig. 7 plots the co-authorship between countries. Although China once again dominates, the collaborations are more scattered and not tied to specific geographical locations (aside from a trend within Eastern and Central Europe). Nevertheless, China, the US, the UK, and Italy do maintain numerous academic collaborations, indicating there is more room for cross-collaboration between other countries with the European and emerging economies outside of Europe.

Final analysis inclusion/exclusion criteria

Having filtered and screened the 319 Scopus sources, only suitable sources were included in the final analysis. Following the initial search, 72 articles were filtered by European countries filter, after which 39 articles were selected based on empirical findings based on all selected keywords. A preliminary screening of titles and abstracts was followed by a review of the articles.

Table 2. Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Full-text peer-reviewed papers based on digitalisation and waste and SMEs in Europe	Research papers published before 2020
Full-text peer-reviewed papers in English	Papers having no keywords 'digitalisation/digitalization' and/or eco-efficiency measures
Full-text peer-reviewed articles that have keywords: digitalization/digitalisation, sustainability, European SMEs, waste	Papers not in English (excluding English abstracts)
	Book chapters, conference articles, short summaries, thesis, opinions, literature reviews
	Papers based on relevant keywords but focus on worldwide rather than Europe
	Papers based on large firms and not SMEs

After the filtering based on the aforementioned inclusion and exclusion criteria, 39 papers were left out of the initial search. More sources were excluded since they either focused on non European SMEs or review papers and hence 29 sources were then extracted after a Scopus search based on peer-reviewed research papers on digitalisation, sustainability, waste and SMEs. As demonstrated in Fig. 8a and Fig. 8b, the number of publications from within the Europe is led by Germany, followed by Hungary, Italy, Slovakia and the United Kingdom while a substantial number of papers are produced in the business management area followed by environmental sciences and social sciences. The distribution of articles does not show a geographical distinction between West and Eastern Europe, meaning research in this field is not confined to a particular region within Europe. These papers are hence reflective of the whole European landscape.

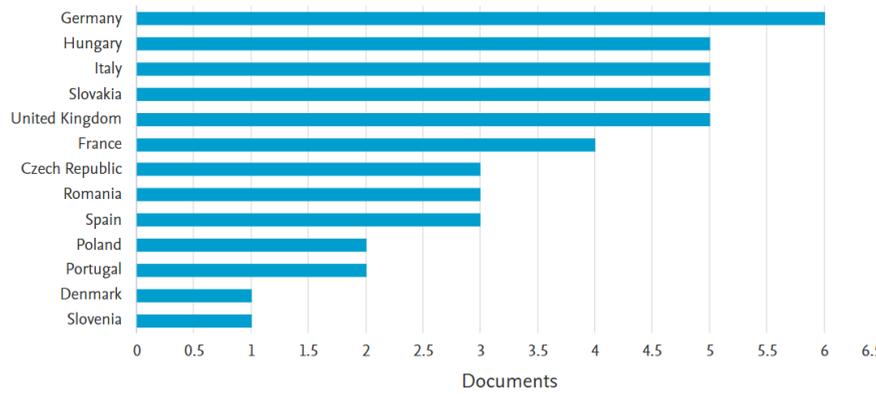


Fig. 8a. Number of articles found on Scopus for each country after applying inclusion and exclusion criteria.

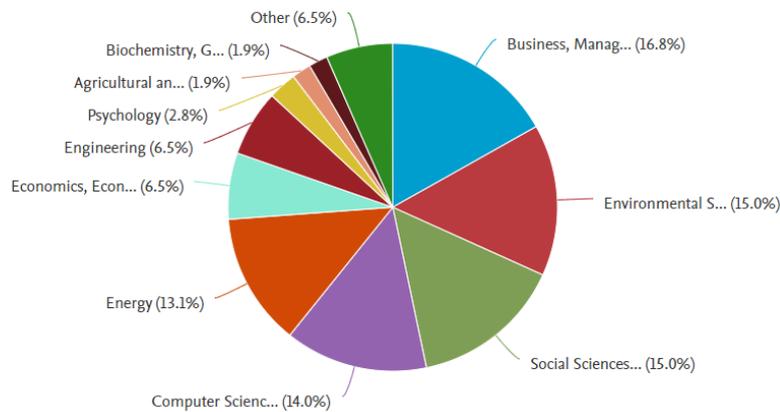


Fig. 8b. Share of articles found on Scopus by subject area after applying inclusion and exclusion criteria.

Discussion

This analysis aims to provide an in-depth understanding of the characteristics of SMEs when implementing eco-efficiency measures. In this review, two major themes are identified: a) the great potential for digital innovations, particularly artificial intelligence and the Internet of Things; b) resource optimization and supportive macro-environmental conditions, although there are challenges to overcome. This section below outlines directions for future research by first discussing the identified themes of the 29 articles selected using the PRISMA 2020 methodology. The findings suggest a consistent emphasis on the role of digitalisation and digital technologies in enhancing sustainability across various industries.

The Table 3. below shows a selection of literature and a summary of findings from Scopus articles retrieved.

Table 3. Key findings of 29 studies that are included in the analysis.

Authors and year	Study type/sector/ country	Key Findings
Ruozzi Lopez et al., 2024	Qualitative comparative analysis with a sample of 198 SMEs of the IT sector certified as B Corps (CBCs).	for sustainable behaviour to become a success, SMEs need to focus on employees, customers, communities, governance and the environment areas and all should be in line with their resources and stakeholder needs.
Kowal et al., 2024	Qualitative data; SMEs in Poland	The degree of digitization of Polish enterprises has increased due to the COVID-19 pandemic, and this study provides an analysis of cognitive value regarding the level of digitization.
Kárpáti-Daróczi et al., 2024	CHAID decision tree method; SMEs in Hungary and Slovakia	Slovak businesses tend to be more optimistic about digitalisation, yet Hungarian and Slovak SMEs differ in their views on how digitalisation affects their costs and resource demands, their product lifecycles, or their productivity.

Avelar et al., 2024	Data from the Flash Eurobarometer 486; SMEs in the EU27 and 12 non-EU countries.	most entrepreneurs within SMEs do not express an interest in pro-growth agendas, which can limit pro-entrepreneurship and pro-innovation talk.
Valero-Gil et al., 2024	Sample of >16,000 SMEs (worldwide)	regarding the phenomenon of convergence of digitalisation and sustainability and concludes that companies that are pro-growth and pro-innovation are more likely to achieve digital convergence and sustainability.
Farace & Tarabella, 2023	Case study; SME operating in the Italian agrifood sector	the digitalisation of production processes can be supported by integrated information systems and can result in an optimum use of resources as well as minimization of waste.
Szabó et al., 2023	Survey; 315 Hungarian SMEs	communication of environmental sustainability, the use of ERP (Enterprise resource planning) systems, and the perception of cultural distance are considered opportunities to facilitate internationalization.
Basova et al., 2023	3D model visualisation tool: SMEs related to the supply chain in Ukraine	proposed solutions to increase the efficiency of supply chain planning in each stage of the product lifecycle.
Silvestri et al., 2022	Longitudinal case study focused on the local development phase of the EU Horizon 2020 project "Eugenius: Argo-food SMEs	offers interesting insights into the multifaceted nature of technology and examines how R&D project participation affects agro-food SMEs in adopting digital innovations.
Isensee et al., 2020	Belief-Action-Outcome framework; employee survey, semi-structured interviews, observation, and document analysis SME from the steel construction and manufacturing sector in Germany.	corporate culture can be both a driver and a barrier to innovation through the manifestation of environmental orientation within eight cultural dimensions.
Borcoși et al., 2023	Quantitative and qualitative methods; Romanian SMEs;	companies with a short and long market presence use digital signatures less than companies with an average market presence.
Fayos et al., 2022	Survey data; Spanish exporting industrial SMEs	digitalisation of SMEs contributes positively to channel integration and sustainability, while channel integration impacts international performance positively too.
Šimberová et al., 2022	Pilot survey; 154 SMEs in the Czech Republic	provides knowledge that can help SMEs to more easily manage threats and opportunities in their digital transformation journey.
Voza et al., 2022	Survey data; Comparative analysis; SMEs in Poland and Serbia	Poland and Serbia show statistically significant differences in reducing harmful emissions.
Dura et al., 2022	Cluster and discriminant analyses; cloud computing solution; Romanian wholesaler SMEs from Hunedoara County	The study presents a cloud computing solution tailored for one of the companies from their sample and transitions it from the average SME performance class to the higher class meaning improved energy efficiency, decreased carbon footprints and lower e-waste.
Tick et al., 2022	Survey; Opinions of SME owners and managers in the V4 countries, Bulgaria and Serbia	divides organizations into two groups (Concerned Inspired and Indifferent Conservatives) and stresses the need for balanced digitalisation, where both sustainability and digitalisation performance matter.
Britzelmaier et al., 2022	Expert interviews; Baden-Württemberg	continuous integration of green controlling can strengthen existing competitive advantages.
Saáry et al., 2022	CHAID decision tree method; 210 Slovakian and Hungarian SMEs;	Slovakian SMEs have a more positive attitude to digitalisation.
Dossou et al., 2022	Lean manufacturing methodology with the DMAIC method, DOE method and GRAI methodology; French SME specialized in industrial cooking food elaboration	proposes a framework that can assist companies in formulating guidelines and transitioning to 4.0-compliant business methods.

Niehoff et al., 2022	Survey-based approach; Brazil (n = 116), to 61% in China (n = 441) and 63% in Germany (n = 104)	polarisation tendencies are a stronger trait among SMEs across all selected countries. The results of this study suggest that the automotive sector could be a suitable research topic.
Costa & Castro, 2021	Quantitative and qualitative analysis;	stresses the importance of SMEs transitioning into digital and provides guidelines on transitioning to e-commerce adoption and exploitation.
Willenbacher et al., 2021	Machine data; Plastic processing SMEs	Since information technology is becoming increasingly important to industrial production processes, this paper aims to use these technologies for sustainable digitalisation within the plastic processing industry to reduce its environmental impact and maximize efficiency.
Denicolai et al., 2021	438 SMEs, including both domestic and international firms	Artificial Intelligence readiness positively impacts the international performance of SMEs.
Ogrean & Herciu, 2021	Romania's SMEs in EU27	reviews Eurobarometer 486 data of Romanian SMEs and EU27 SMEs in terms of perceptions, attitudes and behaviours related to the twin transition.
Hrivnák et al., 2021	Econometric approach; V4 country; knowledge-intensive SMEs	knowledge-intensive SMEs have high resilience towards economic shocks as they are more adaptable to crisis.
MacGregor Pelikanova et al., 2021	Questionnaire survey and semi-structured in-depth direct interviews; 11 Czech hotel SMEs	digitalisation and changes in entrepreneurial strategies have become universal challenges, but not so for sustainability, and corruption and bureaucracy continue to have a negative impact.
Irimiás & Mitev, 2020	Survey study; 270 SMEs and large companies located in a relatively developed Hungarian region	integrating green development into long-term strategies benefits ecosystems.
Zoppelletto et al., 2020	Two-year longitudinal case study; Italian business network operating in the wine sector	provides insights into Network SMEs and other stakeholders such as institutions, competitors and consumers.
Kamišalić et al., 2020	Case studies; Natural fiber-based	favours low-digitalized SMEs to enter and benefit from the already digitalised value chains.

Digitalisation and sustainability transition

There has been considerable discussion of digitalisation across a variety of academic fields. A number of technologies, including big data analytics, artificial intelligence, and the Internet of Things, can support circular economy initiatives (Denicolai, S 2021; Barcosi, C. 2023) and drive business renewal through innovation and technology (Costa, J. 2021). In addition to reducing environmental impact, it can also improve energy efficiency (Willenbacher, M., 2021). Because they are smaller in size and have fewer formal structures, they are more resilient to economic shocks (Hrivnák et al., 2021). Avelar et al., (2024) find that most SME entrepreneurs do not express interest in pro-growth agendas, preventing them from participating in digital initiatives. It is imperative, however, that they adopt pro-growth and pro-innovation strategies since they are more likely to achieve digital convergence and sustainability (Valero-Gil J. et al. 2024). A solution could be to divide organizations into two groups (Concerned Inspired and Indifferent Conservatives) to balance digitalisation, where both sustainability and digitalisation performance matter (Tick A. et al. 2022).

Digitalisation and industrial sector

The adoption of digital technologies by SMEs within different sectors does not come without any challenges. In the post-pandemic era, digital technologies and sustainable business practices hold the greatest potential for contributing to the circular economy (Irimiás & Mitev, 2020). In SMEs, environmental practices vary considerably depending on firm size, profit levels, and managerial characteristics. Within the IT sector, there are five areas where digitalisation has an impact and all contain a human element: employees, customers, communities, governance and the environment heterogeneity of configurations and practices. The findings show SMEs need to focus on these five areas in line with their resources and stakeholder needs to be successful (Ruoizzi Lopez et al., 2024). Additionally, in the agri-food sector, digitalisation is intertwined among firm factors, market dynamics, and institutionalization, all of which are intrinsically related to sustainability and resilience (Farace & Tarabella, 2023). In the steel manufacturing and construction sector in Germany, large companies can achieve significant reductions in carbon emissions while generating a much higher revenue if they can take advantage of sustainable and digital development as early as possible (Isensee et al., 2020). Overall, industry-specific cases provide a bigger picture of the unique challenges SMEs face.

Digitalisation and emerging challenges

Digitalisation brings a significant amount of opportunities, but it also provides a fair share of challenges and threats

one of the biggest challenges is to be adaptable enough to use limited resources and care for the environment (Valero-Gil, J, 2024). Hence businesses, specifically SMEs, need to have tailored digital strategies. (Šimberová et al., 2022) identified five dimensions from their content analysis of Czech SMEs: Industry 4.0; Digital systems, data, and workflow for customer support; Digital security for sustainable development; Competitiveness; and Customer satisfaction and change management to better manage threats and opportunities. On the other hand, digital technologies can help SMEs enter the international market e.g., exporting products and services as empirical results show a positive relationship between export performance and sustainability (Szabo et al., 2023). Similarly (Voza et al., 2022) provided insights into digitalisation's positive effect on reducing carbon emissions within Polish and Serbian SMEs however dealing with e-waste remains a significant challenge. Digitalisation also affects SMEs' costs and resource demands, product lifecycles, or productivity which SMEs see as a significant challenge (Kárpáti-Daróczi et al., 2024). Nevertheless, digitalisation offers significant opportunities for SMEs, but it demands a careful and tailored approach to mitigate risks and challenges.

Digitalisation and waste

Whereas the topics in the previous sections provided an adequate amount of prior art, the literature on digitalisation and waste production turned out to be much sparser. The Scopus search yielded only 4 papers, and these papers apply digitalisation measures to specific use cases of waste management, as will be discussed in the following paragraphs.

Farace & Tarabella, (2023) analyzed the role of digitalisation in the Italian agrifood sector. The authors found that digitalisation measures play a crucial role in optimizing natural resources and reducing waste during production stages by implementing digitally integrated production processes with integrated information systems.

The second study, (Dura et al., 2022) analyzed the performance levels of Romanian wholesaler SMEs in developing practical action plans that support local entrepreneurs in improving efficiency and in adopting circular economy practices. A cloud computing solution was developed for one of the companies from the sample most likely to achieve the transition from an average SME performance class to a higher class. As far as environmental sustainability is concerned, the IT solution consists of the following advantages: an improvement in energy efficiency, a reduction in carbon footprint, a reduction in operational costs, a reduction in electronic waste (e-waste) such as IT tools and equipment which have reached the end of their life cycle (Dura et al., 2022).

The third study by (Sarry et al 2022) focuses on Slovakian and Hungarian SMEs. The authors found that Slovakian SMEs have a more positive attitude towards digitalisation than the Hungarian SMEs. Regardless, in terms of reducing costs and resources, extending the life cycle of products or boosting productivity with digitalisation practices, the findings vary. While the SMEs of both countries agree that digitalisation and sustainability must be incorporated into their business models, they are concerned about the negative impact of digitalisation such as significant amounts of e-waste, not utilising natural resources and high emissions.

The fourth study, (Willenbacher, 2021) created a prototype to help SMEs reduce waste and save energy in the plastics industry using machine learning. There is a high financial effort involved as well as a lack of interest on the part of SMEs and in some cases a lack of human capital as they perceive digitalisation as complex and expensive. The results indicate that digitalisation, and AI systems, are still too new for SMEs, and they prefer their traditional structures.

From these four papers, digitalisation does have a positive impact in specific use cases. It should also be remarked that one of the problems directly resulting from digitalisation, namely e-waste, has been identified and solutions such as utilizing machine learning and AI have been proposed and implemented already. Nevertheless, this area lacks a sufficient degree of research. A solution to this issue is to organize local and international surveys for European SMEs that specifically request data on how digitalisation practices helped or challenged the company. Although the results will be truly diverse in terms of implementation due to the widely different technological backgrounds these SMEs have, general patterns will be identified when common metrics are included, such as workforce, cost of implementation, and choosing certain technologies.

Conclusion

This paper conducted an SLR based on the literature on the intersection between digitalisation and eco-efficiency measures of SMEs in the EU, published after 2020. It examined the state of the art on specific measures such as waste management. This systematic literature review identifies trends and themes related to digitalisation and eco-efficiency within European SMEs. The results showed a significant increase in academic studies on digitalisation and eco-efficiency after the pandemic. Four common themes were identified in the articles that were selected for further analysis: 1) the link between digitalisation and sustainability transition, a key finding indicated that SMEs could rely on their smaller size to adapt faster to changes in policies or markets. This means that the complexity of implementing digital solutions is low, 2). the link between digitalisation and vastly different industrial sectors (agriculture, IT, steel manufacturing, etc.), where it was found digitalisation in the context of sustainability needs to have a particular focus on the human element in the SMEs and the market, and 3) on the link between digitalisation

and emerging challenges where this review identifies guidelines on how to deal with waste challenges and threats such as lack of knowledge of implementing waste management and or eco-efficiency measures. Finally, the study focused on 4) the link between digitalisation and waste management/reduction where it was found that digitalisation through optimisation softwares does help reduce and manage waste, and these software helps to align internal business strategies to eco-efficiency or helps consulting companies in advice for other SMEs. Overall, there is a positive relationship between digitalisation and waste reduction/management, where the benefits clearly outweigh the costs.

However, scientific research on the matter is still scarce, thus, it is recommended to expand on this area, using surveys and moving on to qualitative methods, to address this research gap. Moreover, in this SLR, only one measure of eco-efficiency has been focused on, which is digitalisation for waste management within European SMEs, and only 4 papers dealt with this topic so far for specific use cases. To identify the broader technical considerations and theoretical advances within this topic, more empirical research is required that spans a wider range of industries and European countries. On top of that, there are no cross-sectoral analyses nor an identification of the gaps across various business sectors; this study is planned for a future paper. Nevertheless, the available data, although limited, is still promising, i.e. demonstrating digitalisation does help in specific areas of waste management. Also, this research gap can be further bridged with the help of surveys and other means. As such, the findings of this study already provide proper guidelines for future research, which will help the efforts towards the digital transformation of SMEs to achieve better eco-efficiency. This review is an important contribution to understanding how digitalisation and digital tools have the potential to improve eco-efficiency across the EU. Bringing together fragmented literature, it helps academics and practitioners better understand how digitalisation impacts eco-efficiency, which areas and sectors digitalisation is most effective in, and where future research is needed. This information is also necessary to shape and adjust public policies on competition law and/or sustainability regulation.

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