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Unveiling the relationship between sustainable development and Industry 4.0: A text mining literature analysis

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Abstract

This article aims to assess the evolution of the literature on the link between Industry 4.0 and sustainable development. Through a systematic analysis of the literature, a sample of 234 documents was identified, published between 2011 and 2021. Given the large number of papers collected, the text mining approach was performed to analyze the sample of documents. In particular, the latent Dirichlet allocation model was adopted to group articles in different relevant topics starting from two dictionaries belonging to terms both in the domain of Industry 4.0 and in sustainability. As a result, 11 different topics have been identified that link these two domains. The results showed a strong predominance of Industry 4.0 compared to sustainability models that are very focused only on the environmental aspect. In conclusion, this study emphasizes future research potential by highlighting these existing research areas.

KEYWORDS

corporate social responsibility, Industry 4.0, sustainability, technology, text mining, triple bottom line

1 | INTRODUCTION

The population growth, the push towards consumerism and the greater attention to the quality of life have increased the demand for natural resources exponentially. However, the scarcity of resources places society in a phase of rethinking and organizations must face many operational challenges to redesign processes with a sustainable perspective (Jawaad & Zafar, 2019). Climate change is one of the dominant themes nowadays. One of the main goals of the Paris Agreement is to limit global warming to 1.5°C (The Paris Agreement, 2021). Furthermore, following the resolution adopted by the United Nations General Assembly on September 25, 2015, sustainable consumption and production patterns are one of the main aspects of the Sustainable Development Goals as part of the United Nations 2030 Agenda (UN General Assembly, 2015). To achieve this objective, a reversal of the trend in energy policies is needed to favor the transition towards a cleaner economy, which guarantees the reduction of the demand for natural resources combined with efficient use of consumer goods and converges towards a regenerative economy. Considering the limitations underlying a linear economy, the concept of a Circular Economy (CE) is seen as a solution to harmonize economic growth and environmental protection ambitions.

On the other hand, the fourth industrial revolution and the digitalization of supply chains have led companies to realize that adopting Industry 4.0 (I4.0)/ Internet of Things (IoT) solutions creates opportunities for more sustainable management. These tools could support sustainable production with a combined effort of intelligent systems. Experts believe that I4.0 can offer opportunities for energy sustainability, but there is a lack of empirical research to prove it. Previous studies highlighted how I4.0 contributes to energy sustainability by digitizing the entire value chain, from suppliers to producers and even final consumers (Mohamed et al., 2019). This would allow companies to achieve energy sustainability through better decision-making processes and new business models. Digitization of industrial production will positively influence environmental sustainability. The current technologies of I4.0 produce a cause-and-effect relationship in the manufacturing industry and help activities related to environmental sustainability (Felsberger et al., 2020). According to the authors, this would lead to fewer negative impacts and more positive impacts in terms of materials.

Furthermore, thanks to I4.0, it is possible to study the state of health and evaluate if it can be recovered. The use of smart sensors allows to extend the life cycle of components and reduce the use of additional resources, promoting sustainability. It is no coincidence that we talk about I4.0 for recycling (Blömeke et al., 2020). In the same vein, Tjahjono et al. (2017) highlight how I4.0 can promote sustainable supply chain management. Simulation technologies help create physical products in the virtual world and save energy and costs (Moon, 2016). New sensor-based technologies help SMEs continuously monitor machine usage and energy needs. Advanced technologies improve process efficiency and reduce waste by eliminating defects in the production process (Bigliardi et al., 2022; Moeuf et al., 2018).

Therefore, from the above examples, it can be argued that I4.0 supports sustainable production with a combined effort of intelligent systems. However, there is a scarcity of studies that explicitly investigate the symbiosis between sustainability and I4.0 (Beltrami et al., 2021; Ghobakhloo, 2020). With this aim, this study performs an automated text mining literature analysis of I4.0 technologies within the sustainable domain.

The article is structured as follow. Section 2 presents a brief overview of the interplay between I4.0 and sustainability. Subsequently, Section 3 illustrates the methodology adopted. Next, the results are presented in Section 4. Finally, conclusions and future research directions are included in Section 5.

2 | THEORETICAL BACKGROUND

In the last few years, numerous previous contributions have identified the potential benefits that I4.0 can have on sustainability. According to Ghobakhloo (2020), I4.0 leads to the introduction of new business models such as Crowd-Sourced Innovation (CSI), Manufacturing as a Service (Maas) and Production as a service (Paas), which can offer significant opportunities for economic and social sustainability (Åkerman et al., 2018; Birkel et al., 2019). As for the environmental aspects of sustainability, digitization offers several opportunities to reduce CO_2 emissions caused by industries (Ford & Despeisse, 2016; Kamble et al., 2018), that have represented, in 2021, a quarter of global emissions (IEA, 2022). The use of digital technologies such as the Industrial Internet of Things (IIoT) and Artificial Intelligence (AI) increases the efficiency and flexibility of production and, at the same time, reduces waste and toxic emissions (Jin et al., 2017; Truby, 2020). In addition, I4.0 allows the transition to mass customization, optimizing customer requests contributing to social sustainability (Cai et al., 2019). This has a positive impact on corporate profitability, leading to several advantages from the point of view of economic sustainability as an optimization of the flow of materials, better time to market, optimization of the production space of the plant, efficient use of resources, reduction of waste, better quality and innovation, lower inventory costs (Bigliardi & Filippelli, 2022; Dalenogare et al., 2018; Kamble et al., 2018; Wang et al., 2016). I4.0 also acts as a catalyst for least developed countries to accelerate the process of economic modernization (Ghobakhloo et al., 2021). Therefore, I4.0 is changing how societies produce, consume, trade and live. The digitization of energy systems and the application of digital technologies offer several opportunities for the advancement of the energy sector (Huang et al., 2017). Still, the sustainability improvement thanks to the adoption of I4.0 technologies does not only refer to the energy sector. Indeed, intelligent systems for planning and allocating materials have contributed to saving materials (Yu & Ramanathan, 2015), favoring economic sustainability (Kiel et al., 2017). More specifically, the digitalization of the manufacturing sector favor socio-economic sustainability thanks to the development of reactive and proactive practices that respect the environment (Kamble et al., 2018). The use of technologies facilitates the development of environmental-friendly products (Khorram Niaki et al., 2019). Concerning the social sphere, I4.0 and digital transformation are changing the way human resources work (Longo et al., 2017) simplification and automation of processes, with consequent improvement of the decision-making process, improve the efficiency of human resources (Sivathanu & Pillai, 2018). Using a new tool as the Internet of People (IoP) allows employees and managers to communicate in a more free and interactive way, reducing the communication gap between leadership, middle management, and employees (Corral de Zubielqui et al., 2017). AI and data analytics can offer customized professional development schemes or learning programs based on each employee's experience and personality. In addition, the adoption of visual and simulation technologies offers more effective training methods (Martín-Gutiérrez et al., 2017). Organizations can also use AI and predictive analytics in the recruiting processes to examine the most suitable candidates who have the required skills (Upadhyay & Kumar, 2020). As for the relationship with the customer, digitalization allows manufacturers to develop and implement a lean-agile hybrid production system that better product customization (Ghobakhloo et al., 2021). This has led to production plants satisfying constantly evolving customer requests, both in series and small batch production (Venugopal and Saleeshya, 2019). Automation interoperability contributes to the efficiency and productivity of production by improving control measures (Lee et al., 2015). I4.0 had a significant impact on the labor market (Brougham & Haar, 2018; Sung, 2018). In the last few years, robots, automated vehicles, intelligent machines are replacing humans in numerous activities such as inventory monitoring, quality control and product distribution (Zheng et al., 2018). Experts expect that I4.0 will eliminate most jobs with medium to low qualifications but will compensate by creating new job opportunities in the IT, mechatronics, and engineering area (Ghobakhloo, 2020). I4.0, by 24/7 autonomous production, better process controllability, better production accuracy and quality, real-time monitoring, accident prevention, higher equipment efficiency, less human error, reduces production costs (Beier et al., 2017; Dalenogare et al., 2018; Fatorachian & Kazemi, 2018; Fettermann et al., 2018). It also contributes to corporate sustainability, allowing manufacturers to develop an agile and flexible production system (Brettel et al., 2016; Camilleri, 2022). Recent literature has shown a growing interest in the use of I4.0 technologies to improve the sustainability levels of industries. However, there remains a gap linked to how to channel the efforts made by the authors to have a general vision and understand which the main areas discovered to date are that need further study.

3 | METHODOLOGY

According to Maditati et al. (2018), a review of the literature is carried out to reach two main objectives: (a) to summarize the existing body of the literature on a topic to identify key themes and problems and to suggest future research paths; (b) wrapping any new scientific contribution of existing knowledge and theories.

The purpose of this paper adheres to the first interpretation of the functions of the review processes and is expanded through the definition provided by (Xiao & Watson, 2019). The authors asserted that the progress of knowledge must be built on pre-existing works to push the frontier of knowledge forward. Therefore, it is necessary to know where the current one is positioned. By examining the relevant literature, researchers can understand the breadth and depth of the existing knowledge on the subject and identify gaps to be explored (Xiao & Watson, 2019).

Xiao and Watson (2019) also presented a classification of the reviews, which provides four distinct groups based on their specific purposes: descriptive, test, extension and critical reviews. According to this classification, the present work is configured as a hybrid, as it simultaneously proposes a descriptive and extensive approach to underlying literature. Furthermore, through the descriptive analysis, we intend to provide a comprehensive and systematic picture of the evolution of I4.0 in the sustainable domain.

As is known, several review approaches differ in the analytical tools used, the applications these are intended for, and the scope or extension of the dataset underlying the results that can be obtained. The approach adopted in this article involves a combination of two types of review, known in the scientific field as (i) descriptive analysis and (ii) text mining analysis. This hybrid method allowed researchers to overcome the subjectivity of other synthesis methods in the evaluation and interpretation of the results. In line with previous contributions, this study extracts topics and dimensions from a huge number of articles automatically and methodically using text mining and topic modeling (Bigliardi et al., 2020; Ćurlin et al., 2019; Jede & Teuteberg, 2015). This approach is ideal for identifying unbiased and content-oriented patterns in the articles about a complex scientific phenomenon as the synergy between Industry 4.0 and sustainability. Text mining favors the analysis and visualization of the articles. The use of dictionaries makes easier the exploration of the corpus of texts and the identification of key factors instead of the manual analysis as it increases the level of objectivity. In this automatic coding and synthesis process the researcher do not intervene reducing the risk of biases results (Durach et al., 2017).

3.1 | Descriptive analysis

Thanks to descriptive analysis, statistics are produced on the sample of documents available. This paper borrows the structure of the review from Seuring and Gold (2012), which consists of three phases:

1. Materia Collection: in which the sample under study is defined, the unit of the analysis itself is then defined (e.g., scientific article);
2. Material Selection: in these steps, inclusion and exclusion criteria are defined to consider only articles relevant to the topic under investigation.
3. Descriptive Analysis: the formal characteristics of the collected material are evaluated, the substrate is built for the next phase.

3.2 | Text mining analysis

As research topics are scrutinized by an increasing worldwide scientific community eager to communicate relevant results in peer-reviewed outlets, large bodies of knowledge build-up (Boell & Cecez-Kecmanovic, 2014). As a result, researchers face the challenge of thoroughly reading every publication to contextualize their works. Traditional bibliometrics analysis consists in defining a network that enables to identify the relations between a given input that usually consists in references, keywords, or authors (Linnenluecke et al., 2020). By taking advantage of complex network science, bibliometrics is able to develop graphs that leverage our understanding of given topic and its inner relations. This approach was firstly introduced by Pritchard who coined the term "bibliometrics" in 1969, defining it as "the application of mathematical and statistical approaches to books and other media of communication". Following, Garfield (2007) enriched the discussion in the field by developing historiography with the HistCite program. This tool allows to generate a visual description of the mini-histories of research conducted on any specific scientific topic by collecting all relevant cited articles on a subject in a Web of Science database search.

According to Van Raan (2003) and Bornman and Daniel (2005) the bibliometric analysis represented a first step towards an objective quality analysis of the articles published. Nevertheless, each published article consists in a set of unstructured sentences written in natural language, which contains more information than just the author identified keywords. Moreover, well-established scientific databases such as Web of Science and Scopus index the title, abstract, and keywords, which impel authors to write the words they consider the most relevant to appear in those sections. Therefore, our approach, drawn upon the one also adopted by Cortez et al. (2018), considers the textual contents in the title, abstract, and keywords of each article. It

TABLE 1 Initial search string.

Search string	Hits
TITLE-ABS-KEY ((“circular economy” OR “sustainable development” OR “closed loop” OR “sustain*” OR “triple bottom line”) AND (“industry 4.0” OR “smart factory” OR ((“enabling” OR “digital”) AND “technologies”))	504

TABLE 2 Exclusion criteria.

Criteria of exclusion	Article removed (−)
Initial sample	504
1. Title and Abstract reading	−376
2. Full-text reading	−142
Final sample	234

then borrows from the text mining realm to efficiently provide sense from the contents. The development of automated tools that parse text and summarize results constitutes a relief from such burdensome tasks (Moro et al., 2019). Furthermore, those tools are leveraged by text mining (TM) functions, which aim at processing the qualitative information contained in textual documents (Aggarwal & Zhai, 2012). Specifically, we adopted topic modeling to develop coherent topics that aggregate the most significant literature characterized by a set of relevant terms (Vayansky & Kumar, 2020) related to both I4.0 and sustainability. While topic modeling is a standard technique that can be applied to a given corpus of documents, and it has been used in numerous scientific studies (i.e., to analyze online reviews - Korfiatis et al., 2019), recently, its use proliferated to efficiently analyze large corpus of articles (e.g., Principe et al., 2022, for football performance literature; Kavvadias et al., 2020, for biomedical literature; Mustak et al., 2021, for artificial intelligence in marketing). Therefore, it is deemed as valid and efficient for textual contents literature analyses.

3.3 | Material collection and selection

This phase aims to produce a sample of articles with the most comprehensive theme covering feasible. As a result, data was gathered from the Scopus database. This database has been used in several previous researches as a dependable and high-quality data source for conducting literature reviews (Ahi & Searcy, 2013; Eskandarpour et al., 2015). The search was conducted on August 2021, the search string adopted and the number of papers found is shown in Table 1. A panel of experts in the field assisted in the definition of the query. The search yielded 504 items with no time limit. Following that, we developed two different exclusion criteria to choose the articles focused on the issue under inquiry once the data had been encoded. The first criterion is based on reading each article's title and abstract because the article's title and abstract can contextualize it.

Furthermore, to exclude articles that address sustainability and I4.0 without focusing on the link between them, the title and abstract were submitted to a triangulation process. In the case of uncertainty, each article was examined by two researchers and by a third researcher. A total of 376 papers were rejected based on this criterion. Reading the full text of the remaining papers yields the second exclusion criterion. As a result, additional 142 articles unrelated to the topic of interest were deleted from the list. Table 2 summarizes the results of phase 2.

3.4 | Descriptive analysis

Once the papers were collected, we conducted a descriptive analysis. This step assesses the formal elements of the documents in the sample to characterize and highlight the evolution of the research issue under consideration. According to Ansari and Kant (2017), tables and graphs aid in the presentation of the sample in this phase. The distribution of papers and citations throughout time is depicted in Figure 1. The year 2020 was marked by a surge in articles published (78). Between 2011 and 2015, just seven papers were published. However, after 2016, the literature exploded, with 160 papers published between 2016 and 2020. This growing interest in the junction of the I4.0 and sustainability could be attributed to the rapid development of digital technology in recent years and the growing pressure towards sustainable production and consumption. Furthermore, it is worth noting that the query returned fewer papers in 2021 than 2020 as the research was carried out in August. In terms of citation distribution, there are two peaks in 2017 and 2020, with 545 and 1258 citations, respectively.

The 234 papers were evaluated based on the number of papers published in each journal. There were 109 different journals found. Figure 2 presents the top 10 journals. More in detail, *Economics, Management, and Financial Markets* and *International Journal of Production Research* contribute with 18 articles each, followed by *Benchmarking, Journal of Manufacturing Technology Management* with 10 and nine articles respectively. Other journals provide less than 3% of the total. The articles are polarized between generalist and economic/productive journals. This finding is intriguing because it appears that there is a tendency towards a transition to a sustainable Industry 4.0 that is not limited to a single industry but is at the core of a broader vision of production in general.

3.5 | Text mining analysis

The decision to conduct a text mining analysis was taken owing to the complexity of conducting a manual analysis on such a huge sample of articles (234). The number of articles is similar to the one analyzed by Moro et al. (2019), who also adopted text mining. As a result, this technique made the articles' content analysis easier and more efficient. Furthermore, due to the subjectivity and personal background of the authors, this method prevents generating misleading research findings of the contents. Our approach is similar to the one developed by Cortez et al. (2018). Thus, we

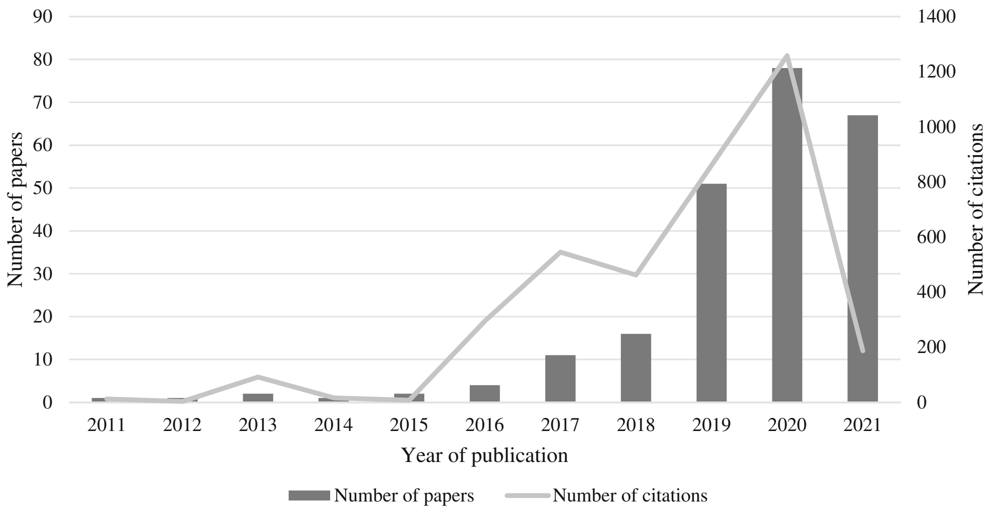

FIGURE 1 distribution of papers per year of publications and number of citations.

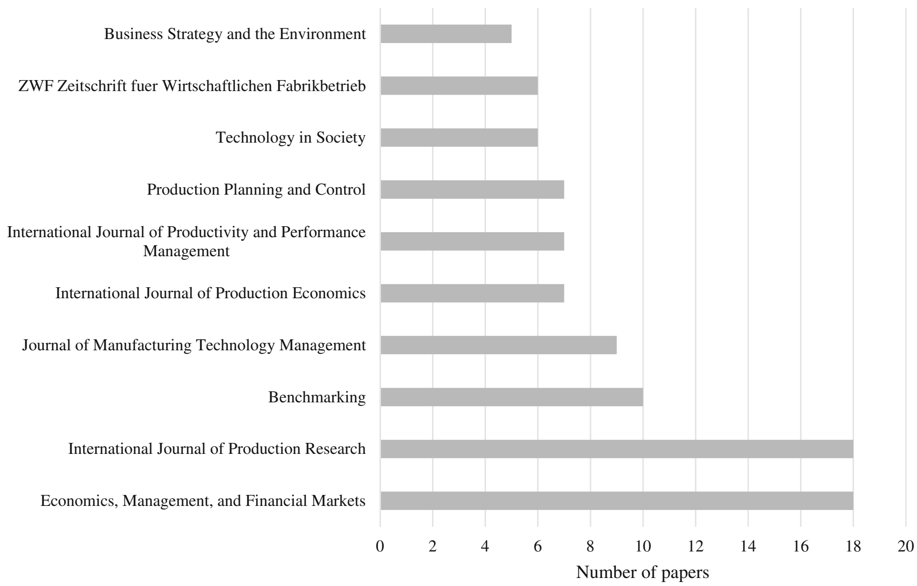

FIGURE 2 Papers per top 10 journals.

created a dictionary that covers more frequent terminology and concepts both in the I4.0 area and in the sustainability field, to focus only on publications about the link between sustainability according to the triple bottom line and I4.0 and enabling technologies. Tables 3 and 4 show the dictionaries for I4.0 and sustainability, respectively. Each one has a list of terms composed of one or more words (n-grams). Because the dictionary definition process is subjective and tied to the authors' perceptions, three researchers carried out the technique repeatedly to promote reproducibility and reduce inaccuracy. Two researchers identified the words associated with each keyword. These words and related terms were then subjected to a third researcher's analysis to determine the final dictionaries.

Furthermore, the words were defined following steps 1 and 2. A good level of familiarity with the themes was gained by frequently reading the title, abstract, and full text of a small set of randomly selected articles, reducing the potential of receiving inconsistent findings. The resulting dictionaries are exhibited in Tables 3 and 4.

The adopted TM procedure included several steps involving the document corpus:

1. To convert everything to lowercase, for a more efficient direct matching;
2. To eliminate extra whitespace (i.e., if the term "digital transformation" had to spaces in-between both words, one of them was removed).

Then, the resulting dictionary of merging both Tables 3 and 4 was used to obtain a document-term matrix only accounting for occurrences of reduced terms (left column of Tables 3 and 4). Thus, if a term on the right column was found, the frequency of the corresponding reduced term in the left column increased. The document-term matrix then contains one row per article and one column per reduced term. Each cell counts the number of occurrences of that reduced term within the corresponding row's article. Such structure is used as input to topic modeling. We performed our experiments using the

TABLE 3 Dictionary for the Industry 4.0 domain.

Reduced term	Similar terms or from the same domain
Industry 4.0	Fourth industrial revolution, smart industry, smart manufacturing, I4.0, industrie 4.0, 4th industrial revolution, digital transformation
Technologies	Technology, key enabling technologies, KETS, enabling technologies, smart technologies, digital technologies, innovative technologies, computer technologies, technological development, technological transition
Smart Industry	Smart industries, intelligent factories, intelligent factory, digital factory, digital factories, smart system, smart systems, smart product, smart city
Additive Manufacturing	Three-dimensional printing, three-dimensional object, layers, layer
Big Data	BD, BDA, big data analytics, big data platform, information, data, data mining, statistical analysis, terabytes, massive data
Cloud	cloud computing, it services, cloud manufacturing, cloud-based design
Augmented Reality	Virtual reality, machine learning, intelligent agent, intelligent agents, simulation, imaginary environment
Blockchain	Distributed database, database, cyber security, encryption,
Internet Of Things	IoT, wireless communication, sensors, computing, wireless sensor network, near field communication, arduino, netsim, z-wave, opnet, telemetry, riot, factory of things, industrial internet
Cyber	Cyber physical systems, cyber physical production systems, cps
Robotics	Advanced robotics, robots, collaborative robots, automation, intelligent robotics, autonomous robots
New Materials	New material, advanced material, innovative material
Integration	Systems integration, vertical integration, horizontal integration

R statistical tool, which contains open-source packages specifically designed for data analysis and, in our case, for text mining, such as the "tm" and "topicmodel" packages. In addition, we adopted the popular latent Dirichlet allocation (LDA) algorithm, which has been widely used for text mining literature analysis (e.g., Cortez et al., 2018; Moro et al., 2019). The LDA takes as input the number of topics, which we computed using the "ldatuning" package from R, and the document-term matrix. The "ldatuning" considers the computations described in the work of Biggers et al. (2014) to enable a more accurate identification of the optimal number of topics. Thus, we adopted it, similarly to what Canito et al. (2018) did. As output, the LDA computes a model that enables quantifying how close a term is to a topic (i.e., to understand if that term characterizes the topic) and how close an article is of a topic (enabling to aggregate existing literature).

TABLE 4 Dictionary for sustainable domain.

Reduced term	Similar terms or from the same domain
Circular Economy	Reverse logistics, closed loop, end of life, products life cycle, remanufacturing
Sustainable	Sustainable production, sustainable practices, sustainable development
Triple Bottom Line	Corporate social responsibility, environmental sustainability, economic sustainability
Recycle	Recycling, reuse, recovery, waste management, disassembly, waste reduction
Sustainable Supply Chain	Sustainable logistics, sustainable product design, sustainable process design, sustainable manufacturing, sustainable purchasing, sustainable customer management
Consumption	Sustainable consumption, energy consumption, material consumption, biodegradable material, water consumption
Green	Green practices, green logistics, green purchasing, green supply chain, environmental issues, green label, eco-label, green management, green economy
Environment	Corporate environmental management, ISO 14000, eco-friendly, ecology, environmental, environmental friendly
Top Management Commitment	Information sharing, trust, customer satisfaction, training, innovation

4 | ANALYSIS OF THE RESULTS AND DISCUSSION

To determine the macro-topics, the data were analyzed based on the frequency of words in the sample documents (Table 5). The most common terms were also rendered in a word cloud to provide a graphical picture (Figure 3). The frequency analysis reveals a degree of paradigm uniformity; among the most common terms (21), they are about distributed in half, with a slight majority in favor of the I4.0 range (12 words). The interesting finding is that big data, IoT, and blockchain are the most often used enabling technologies in the lexicon. This could indicate that most research on sustainability 4.0 has been concentrated on these technologies, while new technologies like additive manufacturing and advanced materials remain underrepresented at present. Another remarkable result emerges considering sustainability according to the threefold line. There is a common trend in studies relating to the environment and a lack of studies on the economic and social domain. In that vein, the term "green" appears more frequently than "triple bottom line".

TABLE 5 Word frequencies for the link between Industry 4.0 and sustainability.

#	Word	Frequency
1	Industry 4.0	924
2	Technologies	428
3	Sustainable	302
4	Big data	206
5	Internet of things	137
6	Top management commitment	131
7	Environment	104
8	Integration	67
9	Blockchain	42
10	Sustainable supply chain	33
11	Circular economy	31
12	Recycle	28
13	Augmented reality	27
14	Robotics	26
15	Cloud	20
16	Green	20
17	Smart industry	16
18	Triple bottom line	15
19	Consumption	14
20	Cyber	13
21	Additive manufacturing	9

FIGURE 3 Word cloud.

Following the frequency analysis, we performed an LDA parameterized to 11 topics, as depicted in Table 6. This analysis is more valuable for this study since it enables us to link I4.0 concepts to the sustainable domain, indicating research trends and current lacks that need further exploration. The second column presents the articles with the maximum likelihood of matching them to each topic. The columns (3–14), for each topic, represent the top six terms with the highest probability of belonging to that particular topic were selected. The lower the beta value explains, the more important the word in that topic. The last columns (15–25) are related to the frequency of the articles on a specific topic over the 10-year range period. From the analysis of the 11 topics, we can see a predominance of the I4.0 domain with seven topics out of 11. While three topics have half of the words coming from the dictionary of the sustainable domain, only one topic (5) has a predominance of the sustainable domain with four terms out of six. This witnesses that academics and practitioners, in the last decade, have focused their attention on purely technological aspects than sustainable initiatives. This evidence is particularly relevant for topic 1, which has only one term related to the sustainable domain and is also the most frequent in the sample. Specifically, the term belonging to the sustainable dictionary is strongly related to the managerial aspect that seems far from the merely sustainable domain. On the contrary, any topics are focused only on the sustainable field. This result further confirms the predominance of technological aspects over sustainable ones. This aspect is relevant because the absence of a parallelism between technological and sustainable development, with an imbalance towards technological evolution could lead to losing sight of the achievement of sustainability objectives. The separation between technological and sustainable development is therefore an issue that must be solved through a rethinking of current business models and the dissemination of a sustainable culture in parallel with the diffusion of I4.0 technologies. The indirect effect that the advent of modern technologies has had in relation to sustainable development remains a less explored topic that needs further study by proposing the concept of the *rebound effect* of digital technologies in a more current key.

As for the synergies between I4.0 and sustainability, we have focused on the first three terms with a value of β lower than 3 in line with previous contributions (Moro et al., 2015). In four topics, the first three terms pertain to the I4.0 domain, which witnesses a strong polarization of the literature towards digital transformation.

Furthermore, we can observe that topics that have terms related both to the I4.0 and sustainability domain (2,4,5,6,7,10,11) have a growing trend in the number of papers published over the years. This is not evident for topics (1, 3, 8, 9) only focused on the I4.0. This result showed considerable interest in the literature for the synergies between technologies and sustainability, especially in the last 5 years. What as more, analyzing each topic individually, four of the seven topics that link I4.0 and sustainability (2,5,7,10) focused on the I4.0 from a broad perspective and not on specific technologies (e.g., big data, IoT, blockchain etc.). This result highlights how the literature has been focused on a more holistic vision relating to or concerned with wholes or with complete technological development rather than with the individual technologies. In addition, topic 2 seems to consider not the triple bottom line of sustainability but the environmental sphere. In this topic, the term sustainability is predominant with a β coefficient of 0.52, followed by I4.0 and environment with 1.78 and 2.62,

TABLE 6 Relevant topics for I4.0 applied to sustainability.

Topic	Nr. Articles	Term 1	β 1	Term 2	β 2	Term 3	β 3	Term 4	β 4	Term 5	β 5	Term 6	β 6
1	45	bigdata	0,95	internet of things	1,1	technologies	2,22	industry40	3	top management commitment	3,64	augmented reality	3,84
2	42	sustainable	0,52	industry40	1,78	environment	2,62	technologies	2,68	top management commitment	2,79	bigdata	4,8
3	26	technologies	0,5	industry40	1,62	bigdata	2,9	sustainable	2,99	integration	3,52	internet of things	3,98
4	25	industry40	0,36	sustainable	2,14	technologies	2,17	bigdata	3,25	integration	4,05	robotics	5,33
5	21	industry40	0,69	sustainable supply chain	2,1	recycle	2,14	top management commitment	2,17	green	2,83	technologies	4
6	18	technologies	0,71	blockchain	1,73	environment	2,54	smart industry	2,83	additive manufacturing	3,3	triple bottomline	3,34
7	16	industry40	0,62	environment	1,47	circular_economy	2,04	sustainable	3,75	top management commitment	3,88	bigdata	4,16
8	14	industry40	1,25	technologies	1,49	integration	1,72	sustainable	2,2	bigdata	2,48	top management commitment	3,25
9	12	bigdata	1,76	internet of things	1,77	industry40	1,86	top management commitment	1,91	technologies	2,17	sustainable	2,44
10	11	industry40	0,41	sustainable	2,06	top management commitment	2,68	bigdata	2,81	technologies	3,94	environment	4,19
11	4	industry40	0,44	sustainable	2,01	augmented reality	2,74	technologies	3,04	top management commitment	3,17	bigdata	3,56

2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
0	0	0	0	0	1	4	2	12	14	12
0	1	0	1	1	1	3	1	12	10	12
1	0	2	0	0	1	1	3	4	11	3
0	0	0	0	0	0	0	3	6	9	7
0	0	0	0	0	0	1	0	6	4	10
0	0	0	0	0	0	0	2	3	6	7
0	0	0	0	0	1	0	0	3	6	6
0	0	0	0	0	0	0	3	4	6	1
0	0	0	0	1	0	1	1	1	4	4
0	0	0	0	0	0	1	1	0	4	5
0	0	0	0	0	0	0	0	0	4	0

respectively. Topic 5 is more centred on the digital transformation of the supply chain management operation. The terms linked to topic 2 are I4.0 ($\beta = 0.69$), sustainable supply chain ($\beta = 2.1$) and recycle ($\beta = 2.14$). Also, Topic 7 is characterized by the digitalization of the environmental sphere of sustainability with the terms I4.0 (0.62), environment (1.47), and circular economy (2.04). This is result is not surprising and remark a well-known trend in which environmental outlook dominated the debate on the synergies between I4.0 and sustainability (Bai et al., 2020; Dantas et al., 2021).

Finally, term 10 pertains to the link between the I4.0 and social aspects of sustainability with the terms I4.0 (0.41), sustainability (2.06) and top management commitment (2.68). On the other hand, analyzing the topic more polarized on the I4.0 (4, 6, 7), there is a heterogenicity in the terms related to the sustainability domain and refer to specific I4.0 technologies. In that vein, topic 4 is constituted by the terms I4.0 ($\beta = 0.36$), sustainability ($\beta = 2.14$), and technologies ($\beta = 2.17$). This topic addresses the link between I4.0 and sustainability with a broader view than topic 6 and topic 7, which are more focalized on specific I4.0 applications. Specifically, topic 6 is characterized by the term technologies ($\beta = 0.71$), blockchain ($\beta = 1.73$) and environment ($\beta = 2.54$); topic 7 is made up by the terms ($\beta = 0.44$), sustainability ($\beta = 2.01$) and augmented reality ($\beta = 2.74$).

As expected, the most frequent terms are broad terms. Particularly, I4.0 appears nine times a (six times as the first term). The second most frequent term is technologies 5 times (2 as the first term). The third most frequent term is sustainable four times (1 time as the first term). It is also interesting to note that between the different technologies, big data and IoT appear two times in the different topics. Excepting environment that appears twice, all the other terms (recycle, blockchain, circular economy, integration, augmented reality, top management commitment, sustainable supply chain) appear only once.

β corresponds to the correlation between the topic and term.

5 | CONCLUSIONS

The paper investigates the link between I4.0 and sustainability. Over the years, sustainability has assumed a significant weight in corporate realities and academic research, prompted by the need for a change of pace in the current economic model, which treats the environment as a "waste reservoir". Therefore, companies have shaped some of their processes to respond to the new paradigm focused on the recovery of materials and products, reducing CO_2 emissions, and virgin material used in their activities. At the same time, the growing digitization initiated by the fourth industrial revolution has generated a very rapid evolution that has materialized with the birth of I4.0. I4.0 made it possible to overcome the traditional factory model by developing a new one. Physical manufacturing plants are connected to platforms and digital technologies, allowing flexible production equipment management and generating a profound process of change in their relationship with technology. In this context, the advancement and diffusion of new I4.0 technologies can enable the implementation of CE practices. However, although the contribution offered by digitization and I4.0 enabling technologies is increasingly pushed both in business processes and in everyday life and, even if the need to build a circular economic model has become an urgency, the academic literature has only recently intercepted the importance of building a bridge between these two issues, making greater insights into the real advantages provided to sustainable practices by digital technologies. Therefore, the paper, through a systematic analysis of the literature and a text mining approach, examined the synergies between I4.0 and sustainability. A systematic literature review methodology was adopted to answer the research questions. After following a systematic review protocol, 234 publications addressing the link between Industry 4.0 and sustainability were chosen. Based on the sample collected, it is possible to infer that the deployment of I4.0 technologies enables new sustainability scenarios. The number of papers published, citations and the diversity of sources utilized by the authors is all on the rise. In particular, the sample of papers selected was published over 10 years, from 2011 to 2021. Most of the papers were published in recent years, beginning in 2019, with the maximum number of works released in 2020, demonstrating academics' growing interest in I4.0 and sustainability. Subsequently, a text mining approach using the LDA was used to analyze the literature.

Consequently, 11 different topics were discovered, each of which was discussed considering the three most relevant terms. The most crucial finding is that I4.0 has resulted the dominating study field in the dichotomy I4.0-sustainability. Other important I4.0 technologies include big data and the internet of things that guarantee efficient waste management, adequate green governance, energy efficiency monitoring with reduced consumption, and associated costs (Li, 2022). The analysis also has shown a strong interest in environmental sustainability concerning social and economic aspects. There is indeed an emphasis on the issues of recycling and the CE.

Regarding the evolution of topics per year, topics with terminology relevant to both the I4.0 and sustainability domains showed a growth in the number of papers published. However, this is not the case with topics solely concerned with the I4.0. This result can be motivated by the growing government pressure in the search for sustainable solutions on the one hand and by the huge funding given for the transition to the industry 4.0 model. In addition, the results provide some potentially interesting research gaps.

The link between robotics, cyber physical systems, additive manufacturing and sustainable developments is under-represented. Therefore, it would be interesting to investigate how the use of these systems favors and facilitates sustainability practices. A second point is linked to the expansion of the synergy that exists between the social and economic spheres of sustainability and I4.0. While issues such as recycling the CE seem predominant, there is still little attention on how technologies enable social and economic sustainability models. In this sense, the contribution of the study is aimed at both practitioners and academics as the analysis of the 234 papers and subsequently the identification of the topics represent a useful to lead researchers towards unexplored areas and themes. In addition, managers based on the topics emerged can identify new areas of investment. Finally, the analysis reveals literature focused on wide-ranging aspects and the concept of technology and I4.0 from a general point of view. Therefore, a greater interest on the part of academics in specific technologies and their sustainable contribution would be required.

Although this study attempted to emphasize the potential links between I4.0 and sustainability, it has a weakness linked to the review procedure used, which may have resulted in the omission of some relevant contributions. Furthermore, the study has some limitations that can become a starting point for future studies. In particular. First, the different identified topics were analyzed in a agglomerated way, subsequent studies could extend the analysis considering them individually. Second, the objectivity of the methodology adopted in identifying the topics leaves room for the definition and characterization of sub-themes that could be qualitatively analyzed through techniques such as thematic analysis. Using a blended method combining the LDA approach with a more qualitative technique could be an interesting avenue for future researchers to take.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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