

Industry 4.0 technologies as a lever for sustainability in the communication of large companies to stakeholders

Industry 4.0
technologies

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Abstract

Purpose – Technological innovation, digitalisation and the Industry 4.0 revolution radically changed business management and contributed to the achievement of sustainability goals. While many studies analyse technological innovation, and Industry 4.0 in particular, the technical aspects of its contribution/impact on sustainability remains partially analysed, especially in relation to Industry 4.0 enabling technologies. This study investigates the contribution of Industry 4.0 enabling technologies on sustainability in innovative firms.

Design/methodology/approach – The sustainability reports of the 50 most innovative companies based on Boston Consulting Group (BCG)'s 2022 ranking is analysed through a content analysis. In the reports, enabling technologies are analysed in relation to their contribution to sustainability.

Findings – The results shed light on the application of Industry 4.0 enabling technologies in sustainability practices based on the communication in the firms' sustainability reports. The results indicate that enabling technologies support the three pillars of sustainability in different business processes.

Research limitations/implications – The results have theoretical and managerial implications that broaden the study of enabling technologies and sustainability while also suggesting a future research agenda.

Originality/value – This study aims to address the gap in the literature regarding the contribution of Industry 4.0 enabling technologies to sustainability.

Keywords Industry 4.0, Sustainability, Enabling technologies, Content analysis, Sustainability report, Innovation, Environmental, Economic, Social

Paper type Research paper

1. Introduction

Technological innovations are a key factor in maintaining and renewing business vitality to ensure survival and development (March, 1997). The last ten years (Akbari *et al.*, 2020) and the pandemic (Alraja *et al.*, 2022) pushed technology development processes to overtake other business processes, from production to customer relationships, not least in sustainability-oriented processes (Aldieri *et al.*, 2019; Dhliwayo and Chebo, 2022). Moreover, the digital transformation is becoming the driving force of innovation (Agostini *et al.*, 2020).

In this innovation scenario, the Fourth Industrial Revolution, also known as Industry 4.0, has been underway since 2012 (Lasi *et al.*, 2014). Today, Industry 4.0 is a well-established topic in the management literature (Ortt *et al.*, 2020; Piccarozzi *et al.*, 2018; Ślusarczyk, 2018). Scholars investigated it from both the managerial and engineering perspectives, making it a highly multidisciplinary topic (Zonta *et al.*, 2020). From a managerial point of view, the innovations introduced by Industry 4.0 changed numerous processes and activities: production methods (i.e. Oluyisola *et al.*, 2022; Ivanov *et al.*, 2021; Saucedo-Martínez *et al.*, 2018; Kovács and Kot, 2016; Sanders *et al.*, 2016), business models (Müller *et al.*, 2021; Grabowska *et al.*, 2020), strategy (Wahl, 2015), supply chains (Pfohl *et al.*, 2015), and human



resources (Vrchota *et al.*, 2019; Hecklau *et al.*, 2017), without neglecting sustainability aspects (D'Amico *et al.*, 2020; Ghobakhloo, 2020; Gupta *et al.*, 2021; Jamwal *et al.*, 2021; Shayganmehr *et al.*, 2021; Lepore *et al.*, 2021).

Researchers and practitioners are increasingly considering sustainability in technological innovations during Industry 4.0 in general. Related to sustainability, numerous contributions in the literature aim to define the link and impact of Industry 4.0 in defining processes, with firms increasingly oriented towards sustainable development (Kiel *et al.*, 2017; Stock and Seliger, 2016; Stock *et al.*, 2018). Hence, the literature at the intersection of Industry 4.0 and sustainability is rapidly evolving and growing to cover different areas (Piccarozzi *et al.*, 2022; Li *et al.*, 2020). Simultaneously, the rapid, progressive development of the digital revolution contributed to the establishment of specific tools of Industry 4.0, known as “enabling technologies” (Martinelli *et al.*, 2021; Wan *et al.*, 2015), widely used by firms (Bravi and Murmura, 2021). Some recent studies (Rußmann *et al.*, 2015; Brunelli *et al.*, 2017; Bortolini *et al.*, 2018; Romeo *et al.*, 2018; Buchi *et al.*, 2020; Leong *et al.*, 2020; Mubarak, 2020) classify some of these technologies as the “nine enabling technologies of Industry 4.0”: additive manufacturing, augmented reality (AR), autonomous robot, Big Data, cloud computing, cybersecurity, horizontal and vertical system integration, the industrial Internet of Things” (IoT) and simulation. Scholars started to investigate the link between Industry 4.0 and sustainability from the perspective of its enabling technologies (Asif *et al.*, 2022; Ramirez-Peña, 2020). In this sense, for example, Yadav *et al.* (2020, p. 1), state that “new technologies directly or indirectly contribute to sustainability. So, it is necessary to explore the enablers that facilitate sustainability adoption”.

Other authors (Jamwal *et al.*, 2021; El Baz, 2022) point out that very few studies investigate enabling technologies and their contribution to sustainability (Bag *et al.*, 2018). Moreover, it is not only important that firms implement sustainable practices but also communicate them to stakeholders to gain economic, competitive, and corporate image benefits (Brand, 2011; Newig *et al.*, 2013; Genc, 2017; Bronzetti *et al.*, 2021). Although the disclosure of sustainable information and practices is not mandatory, its dissemination can enhance a firm's reputation and brand, as well as increase credibility in the eyes of stakeholders (Michelon, 2011; Michelon and Parbonetti, 2012; Hummel and Schlick, 2016; Minutiello and Tettamanzi, 2022). In this domain, no existing study in the literature looks at the role of enabling technologies in sustainability under the lens of communication. This study aims to address this gap in the literature by analysing the enabling tools of Industry 4.0 in relation to sustainability to investigate applications and contributions. We employ a content analysis of the sustainability reports of the world's most innovative companies (Boston Consulting Group [BCG] 2022 ranking <https://www.bcg.com/publications/most-innovative-companies-historical-rankings>). We select the sample under the assumption that highly innovative companies should have adequately and extensively applied the innovations introduced by Industry 4.0 and be able to critically comment on their contribution to the achievement of environmental, economic, and social sustainability goals. This study aims to answer three research questions:

- RQ1. Which enabling tools are mainly associated with sustainability?
- RQ2. What sustainability pillars do enabling tools pursue and what level of sustainability do they enable/contribute towards?
- RQ3. In which activity are they useful for sustainability?

The article is structured as follows. Section 2 provides a brief literature review on technological innovation and sustainability, focusing on Industry 4.0 and its enabling technologies. Section 3 describes the methodology. Sections 4 and 5 report and discuss the results of the content analysis, respectively. The article ends with conclusions, implications, and limitation of the research in Section 6.

2. Literature review

2.1 *Technological innovation and sustainability*

Technological innovation has driven and continues to support business development through improvements and simplifications in all processes, which we can consider as “the engine and accelerator that drives high-quality economic and enterprise development” (Wang *et al.*, 2022, p.1). The historical evolution of technological innovations indicates how these gave rise to real waves of revolution and modernisation of society and business in particular (Daniel, 2010). Technological innovation waves are characterised by an innovation phase, in which new technologies pervade society, and an application phase, in which the actual, concrete use of these leads to a focus on a few innovations. In this stage, the focus is on exploiting and extending existing innovations (van Duijn, 1977). The subject of technological innovations is in some cases controversial, with some authors proposing the concept of disruptive innovation (Christensen *et al.*, 2013).

However, the advantages and benefits of innovations in the economy and other spheres of life are undeniable. Indeed, development and economic growth and improved human well-being are some of the important societal goals achieved through technological innovation (Ghaffari *et al.*, 2017). Today, innovations represent an opportunity for firms to gain and maintain a competitive advantage (Camisón and Villar-López, 2014), improve products and services by meeting consumer demands (Chae *et al.*, 2018), and improve processes in all industries (Li *et al.*, 2006; Szopik-Depczyńska *et al.*, 2020).

Moreover, in recent years, researchers and practitioners paid considerable attention to the contribution of technological innovation to sustainability (i.e. Cancino *et al.*, 2018; Szopik-Depczyńska *et al.*, 2019; Omri, 2020). Our society faces numerous problems, such as the scarcity of man-made natural and vital resources (Coccia, 2014). Industries such as energy, agriculture, health, transport, housing and many others, face challenges given the increasing population and over-exploitation of natural resources (Bigliardi and Filippelli, 2022; Dhiwayo and Chebo, 2022). Innovation must necessarily support processes that solve these problems while ensuring that environmental, social, and economic sustainability goals are achieved (Tsoutsos and Stamboulis, 2005; Ostermann *et al.*, 2022). Studies in this context confirm the positive and driving impact of technological innovations on sustainability (Kuzma *et al.*, 2020); that is, “technological innovation is at the heart of sustainable development” (Anadon *et al.*, 2016, p. 1). Research focus in recent years shifted to observing the recent Industry 4.0 phenomenon to understand how innovations, through the revolutions in the industrial world, are even more oriented towards sustainability (Piccarozzi *et al.*, 2022; Ejsmont *et al.*, 2020).

2.2 *Industry 4.0, enabling technologies and sustainability*

Numerous studies turned their attention to Industry 4.0 from a sustainability perspective, leading to the emergence of several areas of interest, primarily related to the production environment (Jamwal *et al.*, 2021; Ghobakhloo, 2020). The topic of production often brings attention to environmental sustainability in terms of making production processes more efficient and reducing environmental impacts (Oláh, 2020). Subsequent studies moved from environmental sustainability to investigate social sustainability supported by Industry 4.0 (Bai *et al.*, 2020). Other studies investigated not only production but also at other processes/activities related to human resources (Gu *et al.*, 2019), business models (Braccini and Margherita, 2018), and customers (Rantala *et al.*, 2019). Studies on Industry 4.0 and sustainability also aimed to clarify the specific use of enabling technologies (Mabkhot *et al.*, 2021; Murmura *et al.*, 2021). Some enabling technologies received more attention, although such studies are at an early stage of analysis (Song and Zhu, 2017).

In Additive Manufacturing, most academic studies focused on energy consumption and the economic and environmental performance of manufacturing systems (Ford and

Despeisse, 2016; Mani *et al.*, 2014). AR is a widely applied, especially in connection with consumers, and its orientation to sustainability refers to the social sphere. Some studies investigate the contribution of AR to education and tourism (Abad-Segura *et al.*, 2020; Alahmari *et al.*, 2019). Autonomous Robots are often analysed in relation to environmental sustainability, in both manufacturing (Hartmann *et al.*, 2021) and agriculture (Saidani *et al.*, 2020). Empirical research on the influence of Big Data on environmental and social sustainability is still in its infancy (Song and Zhu, 2017). Indeed, both conceptual and empirical research on Big Data is still fragmented, making it difficult to compare and accumulate results and arrive at meaningful conclusions (Dubey *et al.*, 2019). Cloud computing is widely associated with sustainability, especially environmental and social, in many areas of business. Its versatility and ease of use allows its application to business models (Chang *et al.*, 2010), production, business in general (Kumar and Vidhyalakshmi, 2012), and manufacturing (Li and Mehnen, 2013). The literature on cybersecurity is still scant and lacks consensus. The most frequent case of sustainability analysis in relation to cybersecurity is related to e-commerce and social security (Salam, 2020).

IoT is widely investigated in relation to sustainability, as it appears to have significant contributions (Throne and Lăzăroiu, 2020) to environmental (Salam, 2020; Mukhopadhyay and Suryadevara, 2014) and social sustainability (Papetti *et al.*, 2020). Finally, Horizontal and Vertical System Integration and Simulation remain little researched, especially from a managerial perspective, and their contribution to sustainability is unclear.

This brief analysis of the main literature indicates that enabling technologies appear to be linked to sustainability, and their recent application is seeing the development of empirical and theoretical studies on their actual contribution. However, the analysis does not show any contributions or research related to firms' communication respect to technologies in contributing to sustainability.

3. Methodology

We apply a content analysis for this study to answer the research questions through a process of inference from text analysis (Beattie *et al.*, 2004; Krippendorff, 2018). Methodologically (Krippendorff, 2018), the inference in content analysis is based on the logic of abduction (as opposed to deduction and induction; that is, from particulars of one kind to particulars of another kind. Therefore, the answers obtained are not conclusive and have a questionable degree of certainty (Krippendorff, 2018). Within this theoretical framework, we conducted keyword searches of the relevant texts. According to Krippendorff (2018, p. 10), the term content analysis first appeared in the early 1940s studies aimed at decoding the messages contained in the mass media.

We chose this methodology as it is a qualitative approach to avoid disregarding what firms state in their sustainability reports and to understand the characteristics of the information and their relevance and importance to the research questions (Kracaue, 2022). Indeed, to answer our questions, it is not only useful to count and/or measure specific keywords, but it is essential to analyse and understand the essence of the content and the specificities of the information described in sustainability reports. Furthermore, interpretation and the role of the researcher are of paramount importance (Bryman, 2016).

We analysed the sustainability reports of the world's most innovative companies as ranked by BCG. The BCG classification was chosen because it is considered one of the most comprehensive and reliable by both practitioners (i.e. Bloomberg) and prior studies (Bayrak, 2022; Hakovirta *et al.*, 2020). Moreover, using an established classification methodology reduces potential biases. The ranking assesses the capacity of firms to use different forces (i.e. competitive intelligence, strategic partnerships, customer experiences, Big Data, and social network information) in their innovation process (Hakovirta *et al.*, 2020). The ranking is based

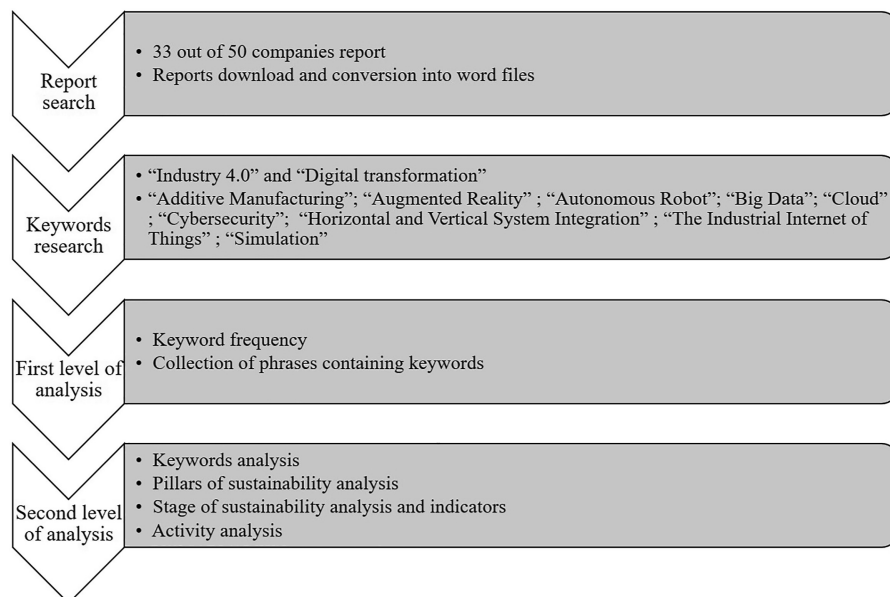
on three factors: global innovation executives' votes for the most innovative companies outside their industry, their votes on the most innovative companies inside their industry, and company financial performance (Bayrak, 2022). Figure 1 outlines the steps in our methods.

The reports were collected from the individual company websites. The available reports (33 out of 50 companies of the sample) were downloaded and converted into word files to start the content analysis. A keyword search was then applied the reports. The reading of the documents is based on a reasoned choice of keywords. We observed company statements in relation to the words "Industry 4.0" and "digital transformation" to obtain general information on these topics. Subsequently, we searched for the nine enabling technologies mentioned above (see Section 1).

Following Beattie *et al.* (2004), we considered the textual unit defined as a sentence containing a single piece of information as the object of observation. As Jones and Shoemaker (1994) pointed out, the coding of the text into particular groups takes place through reference to single words. The first level of analysis consisted of measuring the presence or absence of discourses related to enabling technologies via a keyword search.

The hypothesis implicit in this approach is that the intensity of attendance is as an indicator of interest for Industry 4.0 and enabling technologies. The presence or absence of sentences on topics related to Industry 4.0 and enabling technologies was the primary object of observation. In our investigation, we considered the absolute value of the frequency of use, the ratio in terms of the total number of pages, and the relative weight in relation to the total number of words. Bowman and Haire (1976) and Trotman and Bradley (1981) applied this method to measure the information contained in corporate statements in terms of percentages with respect to the total size of the document.

We counted the frequency of use of each keyword, except for their use in unclassifiable references, such as captions, graphics/tables, the glossary, and various notes that did not provide a relevant informative sentence useful to catalogue the meaning of the keywords. For



Source(s): Authors elaboration

Figure 1.
Overall outline of the methodology

each frequency, we collected and analysed the entire phrase (single information), and then classified each statement. As [Beattie \(2000\)](#) suggested, we tried to highlight the different aspects of the information provided. In particular, the classification of the information in the content analysis scheme involved understanding different aspects of sustainability for each keyword in accordance with the research questions.

In the second level, we analysed the sustainability pillar in terms of environmental, social, and economic goals ([Brundtland, 1991](#)). Then, the level of sustainability was measured and identified the sustainability measurement indicator, if any. The level of sustainability was classified according to [Landrum \(2018\)](#) using the compliance stage that the enabling technologies helped to achieve:

- (1) Stage 1: Compliance;
- (2) Stage 2: Business-centred;
- (3) Stage 3: Systemic;
- (4) Stage 4: Regenerative and
- (5) Stage 5: Coevolutionary.

The stages show a different level of compliance with sustainability and benefits. Stage 1 indicates a focus on sustainability only for regulatory compliance, Stage 2 identifies sustainability aimed at obtaining commercial benefits, Stage 3 aims to systematically change the external environment with corporate sustainability practices, Stage 4 indicates sustainability aiming to regenerate the external environment, and Stage 5 involves sustainability policies that radically affect the external environment on a macro level.

Furthermore, the activity in which the technologies are implemented with a view to sustainability was analysed. All keyword results are catalogued in an Excel database useful for subsequent analysis and comments.

4. Findings

4.1 Sample analysis

The 33 companies were analysed by geographical location and sector. Geographically, most firms are in North America (see [Table 1](#)).

From a sector perspective, the most innovative companies with sustainability report availability are mainly concentrated in four sectors: technology hardware, pharmaceuticals, durable goods and wholesale and retail (see [Table 2](#)).

4.2 Content analysis

The reports analysed had an average of 41,437 words and 109 pages. We identified 146 keywords in as many sentences that report useful information for analysis. An initial frequency analysis of the keywords shows that Industry 4.0, digitisation, and enabling

Table 1.
Regional
representation of the
sample

Region	<i>n</i>	%
North America	20	61%
Asia and Pacific	7	21%
Europe	3	9%
Greater China	3	9%
Total	33	100%

Sector	<i>n</i>	%	Industry 4.0 technologies
Technology hardware	7	21.22%	
Pharmaceutical	6	18.18%	
Durable goods	5	15.15%	
Wholesale and retail	4	12.12%	
Industrial goods and manufacturing	3	9.09%	
Software and services	3	9.09%	
Automobile and components	2	6.06%	
Consumer goods	2	6.06%	
Media and entertainment	1	3.03%	
<i>Total</i>	33	100%	

Table 2.
Sample reports by industry sector

technologies accounts for 4.72% of the number of pages and a frequency of 0.01 % of the total words. This already provides insight into how the selected keywords and their related topics are not widely investigated and communicated in sustainability documents.

Table 3 shows the 146 key words in all the sustainability reports of the sample. The 146 keywords represent a very small percentage of the average words in the reports (0.35% of the sample). Some keywords emerge clearly from the initial analysis. References to “digital transformation” are prevalent, while Industry 4.0 is mentioned in only two cases. This may be because Industry 4.0 is a term coined in Europe, while most of the companies in the sample are American. Cybersecurity, cloud computing, IoT and Big Data appear to be the most reported technologies.

As Table 4 shows, digital transformation is mentioned mostly in the technology hardware and pharmaceutical sectors, Cybersecurity seems to recur in the pharmaceutical sector and cloud computing in the technology hardware sector. The three most frequently mentioned sectors are technology hardware, pharmaceutical and durable goods with 82% of the sample keywords.

The keywords highlight some interesting topics for an initial analysis. First, in relation to company management, we can categorise the keywords into two clusters: one relating to internal processes and the management of company activities typical of the sectors analysed (123 keywords) and the second relating to the management of processes having an external reflection and relations with the environment and various stakeholders (23 keywords). This analysis provides an insight into how technologies support businesses internally and in managing external relationships and processes. The first cluster, which is internal, highlights

Keyword	<i>n</i>	%	Industry 4.0 and enabling technologies
Digital transformation	31	21.26%	
Cybersecurity	29	19.86%	
Cloud	25	17.12%	
IoT	22	15.07%	
Big Data	21	14.38%	
Additive manufacturing	7	4.79%	
Augmented reality	5	3.42%	
Autonomous robots	3	2.05%	
Industry 4.0	2	1.37%	
Simulation	1	0.68%	
Horizontal and vertical system integration	0	0.00%	
<i>Total</i>	146	100%	

Table 3.
Keyword results: Industry 4.0 and enabling technologies

Table 4.
Keyword results and
sectors

	Technology hardware	Pharmaceutical	Durable goods	Wholesale and retail	Industrial goods and manufacturing	Software and services	Automobile and components	Consumer goods	Media and entertainment	Total
Digital transformation	10	10	6	1	0	1	3	0	0	31
Cybersecurity	7	12	2	2	4	0	0	1	1	29
Cloud	11	3	7	0	1	2	1	0	0	25
IoT	8	3	8	0	0	1	2	0	0	22
Big Data	8	6	4	0	0	1	2	0	0	21
Additive manufacturing	5	2	0	0	0	0	0	0	0	7
Augmented reality	3	0	1	0	0	0	1	0	0	5
Autonomous robots	1	1	0	0	0	1	0	0	0	3
Industry 4.0	0	0	0	0	0	0	2	0	0	2
Simulation	1	0	0	0	0	0	0	0	0	1
Total	54	37	28	3	5	6	11	1	1	146

activities, processes, and phases that are typical of business management and addressed by sustainability. The second cluster assesses the interaction with the external environment and the support of technology in reaching the market and managing its needs. This classification is useful for the subsequent analysis of the specific activities/applications of the technologies (see Table 9).

The second level of analysis focused on the sustainability pillar in relation to the keywords. Each keyword highlights a sustainability pillar. The most reported pillar is social sustainability (Table 5).

We compared this result with the keyword mentioned in the paper to understand the link between enabling technologies to sustainability. Tables 6 and 7 show some interesting considerations for the use/application of technologies with a view to sustainability, such as the broad references to cybersecurity in relation to social sustainability, as data security not only for consumers but also for human resources management (see below).

As shown in Table 6, the first three sectors report focus on social and environmental sustainability. In particular, the Technology Hardware sector aims to achieve environmental

Table 5.
Keywords results:
Sustainability

Pillar	<i>n</i>	%
Social	74	50.7%
Environmental	51	34.9%
Economic	21	14.4%
<i>Total</i>	<i>146</i>	<i>100%</i>

Table 6.
Sectors and pillars

Sector	Social	Pillar Environmental	Economic	Total
Technology hardware	20	24	10	54
Pharmaceutical	24	7	6	37
Durable goods	14	12	2	28
Automobile and components	5	5	1	11
Software and services	4	2	0	6
Industrial goods and manufacturing	3	0	2	5
Wholesale and retail	2	1	0	3
Consumer goods	1	0	0	1
Media and entertainment	1	0	0	1
<i>Total</i>	<i>74</i>	<i>51</i>	<i>21</i>	<i>146</i>

Table 7.
Keywords and pillars

Keyword	Social	Pillar Environmental	Economic	Total
Digital transformation	16	10	5	31
Cybersecurity	23	0	6	29
Cloud	13	12	0	25
IoT	3	13	6	22
Big Data	9	10	2	21
Additive manufacturing	3	2	2	7
Augmented reality	5	0	0	5
Autonomous robots	1	2	0	3
Industry 4.0	1	1	0	2
Simulation	0	1	0	1
<i>Total</i>	<i>74</i>	<i>51</i>	<i>21</i>	<i>146</i>

sustainability goals through digital transformation in general. The Pharmaceutical sector focuses on social sustainability with cybersecurity, while durable goods has an almost equal focus on social and environmental sustainability using Cloud technologies.

References to digital transformation also seem to be oriented towards social sustainability, while cloud technologies seem to support social and environmental sustainability almost equally. IoT states a concentration on environmental sustainability.

In terms of contribution to sustainability, 142 keywords (97% of the sample) phrases highlight a positive effect of innovation and/or enabling technology on sustainability. While 4 cases state no explicit contribution of the technology on sustainability. In terms of measurement systems, most reports do not specify a precise sustainability impact indicator (135 out of 146). Some (11 keywords, 8% of the sample) refer explicitly to a measurement, though do not indicate the quantification. Six references affirm an improvement in environmental sustainability in terms of reduced energy use, reduced CO₂ emissions, and improved air quality using IoT technologies, additive manufacturing, and autonomous robots. Four references point to the achievement of economic sustainability by reducing costs using IoT technologies. Finally, one reference states an improvement in social sustainability by reducing CO₂ emissions using IoT technologies.

Table 8 reports an analysis of the level of sustainability achieved through the application of enabling technologies and/or Industry 4.0 innovations.

Most firms aim for Stage 3 sustainability, which benefits both the company and the external environment by contributing to a systematic change. The last analysis observed the scope of enabling technologies within companies by observing the activities/processes (Table 9).

The chief target activity is production. The application of technologies in this case allows for improvements to production processes, phases, or products to meet the objectives of environmental sustainability first, and social and economic sustainability as a function of minimising the use of resources and costs. Many enabling technologies support the human resources sphere in achieving social sustainability, thereby creating wellbeing for workers, safe working conditions, and a favourable environment. Finally, an important contribution is that of data management technology, which again supports the achievement of social sustainability goals often associated with the application of cybersecurity for data security and privacy protection.

Table 8.
Stage of sustainability
reached

Stage	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Total
<i>n</i>	0	39	93	14	0	146
%	0.0%	26.7%	63.7%	9.6%	0.0%	100%

Table 9.
Activity/process of
technologies and
pillars

Activity	Social	Environmental	Economic	Total
Production	18	42	9	69
Human resources	24	1	6	31
Consumers and society relationship	19	0	4	23
Data management	11	3	2	16
Research and development	1	2	0	3
Decision-making	0	1	0	1
Infrastructure	0	1	0	1
Logistic	0	1	0	1
Risk management	1	0	0	1
Total	74	51	21	146

Analysing the keywords associated with the activities/processes indicates that in production, the most common tools is IoT and Big Data, as well as generic digital transformation (see Table 10). Further, in the case of customer relations, digital transformation is mentioned often along with cybersecurity. Cloud technology seems to be most associated with sustainability in activities involving human resources. Finally, the most frequently mentioned tool for data management is cybersecurity.

We can synthesise the main results into a model that can provide an overall and synergetic view of the contribution of enabling technologies to sustainability and the most relevant aspects. Figure 2 provides the overall view of only the results related to enabling technologies.

The overall model highlights the contribution of the various technologies to firms' internal and external activities/processes. Externally, consumers and society in general seem to benefit from specific technologies such as Augmented reality, robots, and cybersecurity. Similarly, it is not always easy and straightforward to see how these activities/processes also benefit in terms of sustainability. In fact, although the model tries to create a unified view of results, it hardly contributes to providing a link between activity/process and sustainability benefits. Moreover, as we already pointed out, indicators often remain generic and not useful for understanding the specific contribution of enabling technologies to sustainability in individual activities/processes.

5. Discussion

The results indicate some contributions of Industry 4.0 enabling technologies to sustainability. We can outline some important considerations related to the research questions.

(1) Which enabling tools are mainly associated with sustainability?

In many cases, we find a generic reference to technology for the keyword digital transformation. Many sustainability reports do not specify a precise enabling technology but trace the achievement of a pillar of sustainability results back to generic technological evolution. The results show how digital transformation drives sustainability in all three of its pillars.

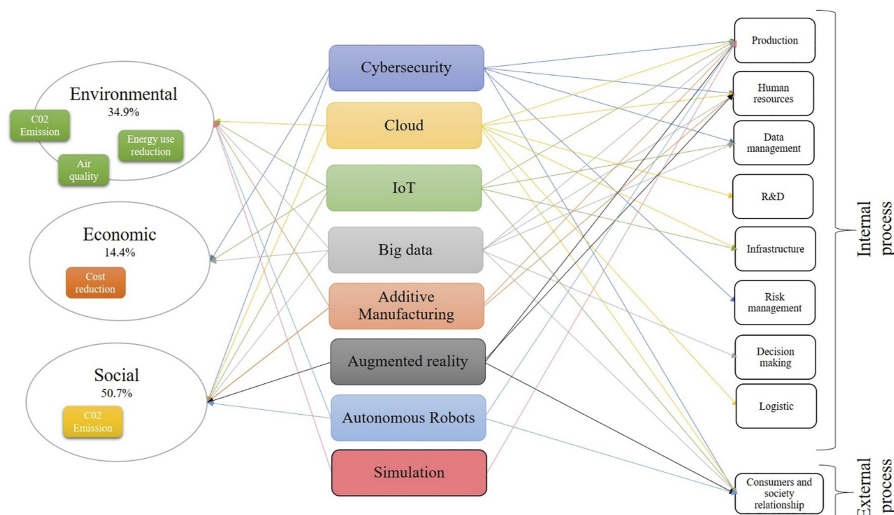
The first enabling technology typical of Industry 4.0 emerging from the content is cybersecurity. Cybersecurity is closely linked to social sustainability in production, human resources, and consumer and social relationships. This technology allows social sustainability in the sense of providing guarantees, security, and protection of privacy, especially in the processing and dissemination of data (Sinha *et al.*, 2015; Michael *et al.*, 2019). Indeed, privacy, data rights, and cybersecurity are fundamental to maintaining the freedom and dignity of the individual. The focus on cybersecurity and the implementation of information and privacy protection models is part of the care and attention to the customer and society at large to create loyalty and trust.

The second most frequent technology mentioned is cloud computing, which is associated with social and environmental sustainability goals and often linked to production activity (Garg and Buyya, 2012). Cloud-based systems are fundamental for the exchange of information and communication both internally within the firms and externally (Olawumi and Chan, 2022). Internally in particular, cloud computing can convey information that can support production in processes aimed at environmental sustainability and human resources in activities focused on social sustainability.

IoT is a technology used widely to achieve environmental sustainability, especially in production (Nizetić *et al.*, 2020). In the sectors where it is most applied (hardware technologies and curable goods), IoT technologies serve to simplify processes, ensure better system efficiency, and ultimately improve product quality and thereby achieve sustainability goals. IoT are sustainably transforming the manufacturing sector in terms of green manufacturing (Mao *et al.*, 2019), zero-waste manufacturing (Kerdlap *et al.*, 2019), efficient manufacturing,

Table 10.
Keywords and activity/
process of technologies

Activity	Production	Human resources	Consumers and society relationship	Data management	R&D	Infrastructure	Risk management	Decision making	Logistic	Total
Keywords										
Digital transformation	12	7	10	0	2	0	0	0	0	31
Cybersecurity	11	6	4	7	0	0	1	0	0	29
Cloud	9	9	1	4	1	0	0	0	1	25
IoT	16	0	3	2	0	1	0	0	0	22
Big Data	10	5	2	3	0	0	0	1	0	21
Additive manufacturing	5	2	0	0	0	0	0	0	0	7
Augmented reality	2	1	2	0	0	0	0	0	0	5
Autonomous robots	2	0	1	0	0	0	0	0	0	3
Industry 4.0	1	1	0	0	0	0	0	0	0	2
Simulation	1	0	0	0	0	0	0	0	0	1
Total	69	31	23	16	3	1	1	1	1	146



Industry 4.0 technologies

Figure 2.
Overall model

Source(s): Authors elaboration

and sustainable supply chains (Wang *et al.*, 2018). IoT is also transforming the waste management arena, for example, to treat and significantly reduce waste (Ferrari *et al.*, 2020).

Finally, the third most recurring technology is Big Data, which seems to support environmental and social sustainability. The areas of application are production, human resources, and to a small extent, a reflection on the consumer and society in general. In these contexts, Big Data can provide the company with external and internal information, thereby supporting decision making and the organisation of the structure to achieve social and environmental sustainability (Dubey *et al.*, 2019). Big Data can support firms in risk mitigation, including margin improvement, employee education, skills development, and labour relations (Wu *et al.*, 2017). In production that aims to achieve environmental sustainability, Big Data improves resource allocation and efficiency, provides realistic and quick sales forecasts, and helps reduce inventory and waste, saving energy and resources (Etzion and Aragon-Correa, 2016).

- (2) What sustainability pillars do enabling tools pursue and what level of sustainability do they enable/contribute towards?

The results show how digital transformation, Industry 4.0, and enabling technologies support the implementation of practices oriented towards social and environmental sustainability. Social sustainability is mentioned most frequently (74 occurrences, 50,7%). This result can be interpreted in light of the recent pandemic, which highlighted and broadened the focus not only on environmental sustainability issues but also on social ones (Sajjad, 2021). digital transformation understood in a broad sense supports the development of human resources competencies by training talents to create a sustainable working environment that aims to create lasting value for the internal and external environment. Moreover, the sample firms inform stakeholders in their sustainability reports about the use of cybersecurity not only for data protection and consumer privacy but also for internal learning platforms, skills development, and workplace improvement (Melnik *et al.*, 2022).

Through the Cloud, some companies, in cooperation with the Ministries of Education in the regions where they operate, can offer various technology training programmes for students and

unemployed young people to help them find better employment. Such practices improve employability and support social and economic improvement. cloud computing, combined with other technologies such as drones and artificial intelligence, can improve environmental sustainability by decreasing environmental impacts and simultaneously supporting human work by making it easier.

Environmental sustainability follows social sustainability in terms of frequency (51 occurrences, 34,9%). Enabling technologies support companies in addressing environmental sustainability especially, in the production process. Process improvements, waste reduction, and better planning of the raw resources are the main benefits. IoT is one of the most widely used technologies in manufacturing and enables the firm to monitor energy use in plants and increase their efficiency, facilitates the development of new operational and business models in areas such as remote predictive maintenance and optimised energy use, also allows customers to assess and improve their energy consumption (Salam, 2020). IoT is often integrated with Cloud solutions to further improve environmental performance (Benkhelifa *et al.*, 2014). Moreover, Big Data supports social and environmental sustainability as it enables a wide range of up-to-date and constant information on the internal and external environment, helping to achieve optimum levels of sustainability.

Moreover, the Landrum (2018) classification can highlight how most activities ensure the achievement of Stage 3 systemic sustainability (64%). This stage indicates an intermediate level of sustainability that allows the company to implement practices and/or actions for internal change that succeeds, even if only to a small extent, in influencing the external context by producing a positive effect. Twenty-seven percent of the sample were in Stage 2, indicating weak sustainability often aimed at seeking commercial and economic benefits rather than an intent to change the internal/external context. This is the case with economic sustainability achieved through savings in production costs generally. Only a few firms in the sample aim for the regenerative stage (10%). This stage leads to positive internal results within the company that spill over decisively to the external environment, creating a considerable external sustainability benefits, be it economic, environmental, and/or social. For example, in production activities, Additive Manufacturing and Autonomous Robots are advantageous in environmental sustainability for both the company and the external environment (reduced energy costs and simultaneous use of energy resources, or waste minimisation). Again, the sample firms showed huge improvements in social sustainability using Big Data for both the company's human resources and the consumers in the external environment.

(3) In which activity are they useful for sustainability?

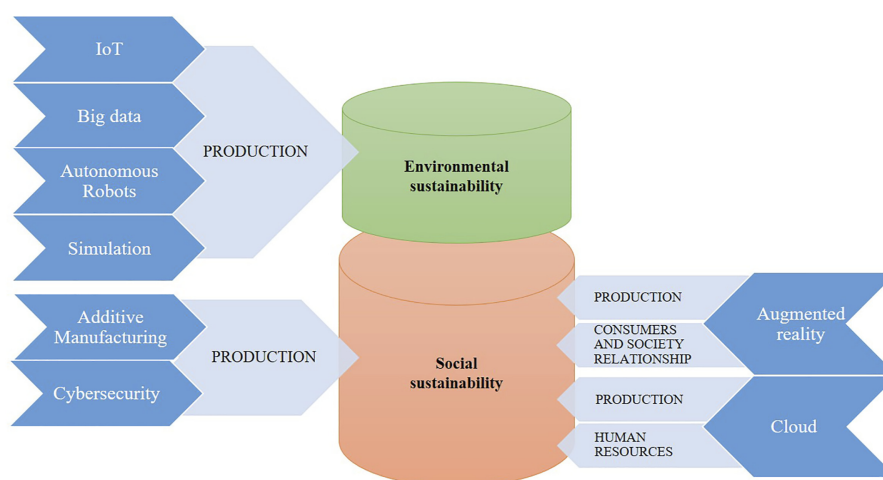
The analysis shows how certain technologies support sustainability in specific areas. As might be expected, production emerges as the predominant activity. This outcome is logical given the nature of Industry 4.0 and the enabling technologies that originate precisely for industrial and manufacturing purposes, where their usefulness is eventually identified in other contexts. Digital transformation supports environmental sustainability especially, and IoT seems to be the most common enabling technology, often in combination with cloud computing. Interestingly, digital transformation and cloud computing supports social sustainability in human resources. The focus on human resources is increasing and Cloud technologies are mentioned in several cases as a valuable tool both for training personnel and sharing information to substantially improve the conditions of workers and the operating environment. Digital transformation also has a positive impact on the external environment, primarily in stakeholder and consumer relations. The recent pandemic certainly prompted companies to equip themselves with technologies to overcome the regulatory barriers of distancing, and such innovations greatly contribute to social sustainability by sustaining stable, albeit virtual, relationships and a constant flow of information with consumers.

This is also possible due to the constant contribution of enabling technologies (Big Data and cybersecurity in particular) with respect to information management. Data management and decisions on risk management are also technology-supported activities that can realise social, economic, and environmental sustainability. In light of the evidence from this discussion of the research questions and the overall view in Figure 2, it is interesting to extrapolate the main evidence emerging from this research. Figure 3 summarises the main applications of enabling technologies across business activities and in achieving different pillars of sustainability.

Production processes see the most applications of enabling technologies. This seems obvious, though the affected pillar of sustainability is not. Indeed, alongside numerous applications that support environmental sustainability (IoT, Big Data, Autonomous Robots, and Simulation), it is striking how some technologies contribute to social sustainability. Additive Manufacturing, cybersecurity, AR, and cloud computing, not only through internal production and human resource management processes, but also through processes affecting consumers and society at large, successfully support social sustainability. This summary view of the results lays the foundation for thinking about the still nascent applications of Industry 4.0 technologies (Jamwal *et al.*, 2021). Indeed, production processes represent the original application of Industry 4.0, which has since expanded to all business processes (Zheng *et al.*, 2021). The enabling technologies are remaining in the cognitive and study phases in companies that are still unable to appreciate and exploit their full capabilities and interaction (Sigov *et al.*, 2022).

6. Conclusion

The study shed light on the application and communication of Industry 4.0 enabling technologies in the sustainability practices of innovative companies through the firms' sustainability reports. We find infrequent mentions of the enabling technologies and the general terms digital transformation and Industry 4.0. However, the few mentions provide an overview of the most common technologies applied and their connection to the pillars of sustainability in various sectors and activities. In general, provides positive support for sustainability. The stage of sustainability attained shows a propensity for systemic sustainability that therefore involves, even if only to a small extent, the external



Source(s): Authors elaboration

Figure 3.
Main findings

environment. The information in the reports is often of a general and broad nature and does not go into the details of sustainability aspects except in a few cases, that mention, for example, the evaluation parameter of sustainability achieved (CO₂ emissions, waste reduction and energy use). The limited information can be justified by the wide audience of the sustainability report, as all firms' stakeholders have different knowledge bases and information needs according to their interests and roles. Moreover, the use of enabling technologies in achieving sustainability is not always apparent. Some tools are mentioned together, but it is not always possible to deduce the basic structural model in which the various innovations fit and interact. What is lacking is a systemic vision that also calls for a business model that can accommodate the enabling technologies, alone and in combination, and achieve sustainability, which must also be measured. Therefore, we find a lack of concrete analysis and measurement of sustainability achieved through technological innovations, and enabling technologies in particular. Measurement systems integrated with corporate information systems could be useful and of considerable support in speeding up and objectivising decision-making at all corporate levels. What emerges is that the application of enabling technologies in relation to sustainability goals is not limited to the company's operational activities, but also enables support for tactical and strategic activities. Therefore, from a decision-making perspective and in the implementation of a sustainability-oriented strategy, managers could benefit from an informative and subsequently practical contribution to sustainable development.

6.1 Practical and theoretical implications

From a managerial perspective, the results provide insights for managers and entrepreneurs who want to implement sustainability practices through innovative tools. The information on sustainability, although still scant, offers useful insights into the different sectors and activities that indicate some interesting applications of the enabling technologies. The results provide an initial insight into the possible application and usefulness of the enabling technologies in business processes and activities. Practitioners can begin the process of integrated digitisation on the basis that production and sustainability goals benefit from new technologies. The results show how the contribution of technologies pervades human resources, consumer, and data management to sustainability. Moreover, the adoption of technological innovations does not necessarily require large investments. Big Data is a main enabling technology applied and discussed in the sustainability reports (Pence, 2014), that is affordable for firms of all sizes. The sectoral analysis provides other important information. Digitisation and its technologies are widespread in many industries (technology hardware, pharmaceutical and durable goods) with the aim of achieving sustainability outcomes. The heterogeneity of the sectors analysed substantiates a high flexibility of adaptation and use of enabling technologies that can be shaped and integrated with different business dynamics. The main issue is the need for appropriate training of staff and managers to understand the opportunities arising from these innovations, understand the appropriate integration with business processes and optimise their use from a sustainability perspective. cloud computing, Big Data and IoT are adaptable, flexible and sustainability-oriented, but they require training and knowledge to be applied effectively and efficiently in the business system. Moreover, the results provide a view of sustainability communication by firms, through documents that are not required but strongly recommended for stakeholders' understanding of the business. Information on sustainability and technological innovation can improve stakeholders' perceptions of the company and develop greater awareness and loyalty, especially amongst consumers, who are increasingly interested in sustainability issues. From a theoretical point of view, the paper fits into a broad strand of Industry 4.0 and sustainability studies,

detailing not only on a general level how digitisation contributes to sustainability, but providing a specific analysis on enabling technologies in the communication lens of firms.

6.2 Limitations and future work

This study also has some limitations. The most important is the subjectivity of the classification method (Weber, 1995; Krippendorff, 2018). Manual search without the support of software can enable researchers to appreciate the content of the reports and the phrases in which the keywords are contained, as well as analyse the main aspects by understanding the context of the keywords. However, analysing individual phrases suffers is subjective, which may, to a minimal extent, lead to a broad or distorted interpretation of what the reports contain.

Furthermore, the sustainability report, while useful for understanding the sustainability dynamics and practices of companies, may not provide much detailed information. Some aspects and applications of enabling technologies may be omitted because they are too technical and not suitable for a very wide audience with different background knowledge. In future research, it might be interesting to analyse the reports of small and medium enterprises to understand the degree to which the enabling technologies are used in smaller contexts. The analysis of sustainability reports could also be supplemented with analyses of annual reports or other disclosure documents to integrate more information and take a more systemic view. Moreover, as emphasised, there is a need not only for a system to measure the sustainability achieved through enabling technologies but also for accurate business models and information systems that enable the broad and synergetic function of information at all company levels.

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