

## Article

# The Degree of Contribution of Digital Transformation Technology on Company Sustainability Areas

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**Abstract:** The impact of new digital technologies creates challenges for the digital transformation process in company sustainability areas. The purpose of this study was to determine the degree of contribution of digital-transformation-enabling technologies to company sustainability areas of three pulp and paper manufacturing companies in Brazil and relate it to the UN Sustainable Development Goals (SDGs). Through a systematic literature review based on the PRISMA method, we sought to assess the key concepts of sustainability and the implementation of digital transformation (DT) through its enabling digital technologies. A field study was conducted in three Brazilian pulp and paper companies to assess the degree of contribution. They are leading companies in the paper and cellulose industry in Brazil. The results obtained indicate that the companies in this sample are still in a growth process regarding the use of digital technologies in their sustainability areas. Only one digital technology, cloud computing, appears relevant in one of the companies studied, which differs from the theoretical framework presented by the literature. To achieve the SDGs goals, countries, especially emerging ones, need to develop their technologies and their business and improve the results that relate to sustainability. The research method applied in this study can be replicated to other companies where the impact of digital transformation technologies on company sustainability is critical.

**Keywords:** digital technology; digital transformation; sustainability; SDGs



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## 1. Introduction

DT refers to the idea of new products or services driven by the increasing number of innovations and use of digital technologies. This movement toward products is due to the fact that DT must be guided by a broad business strategy [1]. The purpose of DT is restricted to one group or business area [2] as it runs through the company as a whole. The potential of digital technologies enables the development of new sustainable business models, which still need to gain legitimacy to be accepted [3].

A company that seeks good economic performance needs to meet the requirements of its performance in the economic, environmental, and social areas [4]. In the environmental scope, sustainability is present in the strategy of companies with the purpose of minimizing environmental impacts, providing business benefits, and increasing the performance and competitiveness in the market in which it operates [5].

The impact of Information and Communication Technologies (ICTs) on the SDGs is already the subject of studies such as that of [6], in which it was identified that the intensive use of ICTs does not imply the improvement of sustainability, unless it is inserted in strategies aimed at achieving the SDGs.

Ref. [7] presented the perspective of some technology companies with sustainability actions: Microsoft Corporation states that “there is massive potential for technology to revolutionize our environmental assessment practices, so they can be conducted faster and cheaper, and—for the first time—be able to operate at a truly global scale”, while HP Inc. reported in an article a “Sustainable Forests Collaborative Initiative” that looks “to protect, restore and improve the responsible management of forests, and to estimate the carbon and nature co-benefits of forest restoration and improved forest management”.

Based on the research carried out, there is a gap in the literature when relating the DT in company sustainability areas or supported in the achievement of the targets of the SDGs. Although the SLR resulted in 70 articles with varied indications of DT technologies related to the theme of sustainability, the analysis of the WoS academic database showed that sustainability-related DT presents a higher concentration in the following areas: Green Sustainable Science Technology (70), followed by Environmental Science (61), Environmental Studies (56), and Business (42). Emerging countries, such as Brazil, need to evolve their business capabilities and improve their performance in order to meet the SDGs [8]. It is now essential for companies, in all countries, to carry out corporate social responsibility activities to achieve the purposes of the SDGs, as companies cannot ignore social issues [9].

Given the relevance of the incorporation by society of ICTs in course, and the demand for social engagement of companies, this study aimed to analyze and verify the degree of contribution in the application of enabling digital technologies of the digital transformation for company sustainability. The systematic literature review underpinned the elements (technologies in this study) and the statements about the elements that make up the questionnaire sent to companies and respondents, through an adaptation of a model previously tested by [10], which adopted elements and statements to define the degree of competitiveness contribution of automotive companies.

Based on authors [11,12], Industry 4.0 (I4.0) and Digital Transformation (DT) are treated as being similar in the use of digital technologies; however, I4.0 and DT are different ways of looking at the use of these digital technologies in companies. I4.0 is a way of indicating the industrial revolution in time, while DT is an indication of the use of digital technologies in all types of businesses and in society, which leads us to the concept of Industry 5.0 (I5.0). It is rather new, and there is still no consensus on its definition; however, [13] stated that I5.0 comes from I4.0 paradigms and technologies, which mainly address innovation to drive the transition to a more sustainable and human-centered industry. That said, it allows moving the focus from shareholder to stakeholder value and everyone involved in the man-machine issue.

## 2. Research Background

Based on the research carried out, there is a gap in the literature when relating the DT in company sustainability areas or supported in the achievement of the targets of the SDGs. The authors defined the strategy of considering for analysis articles that more specifically address DT technologies related to the theme of sustainability.

Considering that the main point of this article is to determine the degree of contribution of relevant technologies of DT to company sustainability, the theoretical framework comprehensively addresses the concepts of digital transformation and sustainability.

### 2.1. Digital Transformation (DT)

DT is under construction, and it can be interpreted as a process of digital action in the company to better serve customers. It is characterized as a change in the strategy and culture of companies [14].

The process of adopting DT should be well planned and proposed with the stages of initiation and execution aimed at meeting the proposals established by the company [15]. Although it involves implementation of new technologies, DT is not limited to that point, as it also reshapes the business with the purpose of creating value for the customer and the company itself [16]. The implementation of DT permeates the various business areas in the pursuit of value creation and process optimization through fundamental capabilities designed to support the ordering of ongoing activities [17].

DT initiatives build on existing legacy systems in the enterprise that enable the new technologies being offered, a characteristic that is distinct from the approach in which technology is the driving force behind DT [18]. Furthermore, [9] proposed that DT in companies is initiated by customers and oriented to meet their needs through innovation and redesign of their products and services in order to extend added value to all stakeholders.

DT has some characteristic triggers, and they are called: mobility, analytics, social media, cloud computing, and the internet of things [19]. Additionally, enabling technologies are also considered triggers for DT: big data provides predictive insights for outcomes, drives real-time operational decisions, and reinvents business processes [20]. In this perspective, the IoT uses sensors intended to capture and store data in a structured way [21] through the modules intended to provide the functionalities that enable business-related interactions [22] making DT and society compatible; AI (Artificial Intelligence) is used in logistics to improve supply chains [23], and when coupled with other technologies, it enables automation of production lines, as well as data exchange between digital technologies and manufacturing processes [24], generating business opportunities for development and wealth creation [25].

Approximately 70% of DT initiatives fail, without having achieved their proposed goal, if the company is not ready to change [1]. For these authors, not even the investment of financial resources in digital technologies guarantees the success of DT implementation if the company is not structured for the new organizational approach because, in this perspective, what will be observed is a greater exposure of existing weaknesses. The DT process begins in understanding four critical values—impact, speed, openness, and autonomy—which position themselves as cultural to the company and thus potentially as obstacles to its implementation [26].

Although challenging, the change in culture is positioned as an opportunity to incorporate sustainability aspects into the business model adopted by the company [27].

## 2.2. Sustainability

The change in corporate thinking highlights social responsibility [28], society, and its interests in its management [29]. The Triple Bottom Line, or tripod of sustainability, has three spheres: the social, the environmental, and the economic. The social sphere is represented by respect for human capital and society; the environmental sphere is represented by how the company uses nature's resources or produces an impact on nature without harming the natural ecosystem; the economic sphere is represented by the profitability and liquidity of the company [30].

Sustainability is a broad subject, and it is worth mentioning that the circular economy, the green economy, and the bioeconomy are all matters that belong to the theme. It is necessary to understand that circular economy and bioeconomy refer to resources, while green economy refers to the processes involved [31]. Sustainability has been incorporated into the circular economy from the perspective of reusing resources [32]. By thinking about future generations, companies incorporate sustainability principles into their operations for the purpose of staying in the market in which they operate and aggregate value to DT [33].

It was found, in an evaluation of the benefits of I4.0 in companies, that sustainability is one of the main benefits that result from the application of digital technologies, as companies expand their visibility with increased added value by being sustainable [34]. DT innovation and technologies such as cloud computing, cyber-physical systems, and 3D printers are considered to be influencers of the sustainable business model [23]. For

example, a 3D printer (additive manufacturing) provides great support for construction by enabling solutions to climate, energy, and environmental challenges [35]. In this context, the important role of the Information Technology (IT) area stands out, called green IT, strongly implementing a sustainable development program [36].

Regarding sustainability, the United Nations Organization [37], an international organization that brings countries together voluntarily and aims at peace, cooperation, and development of countries, has proposed 169 sustainable targets to be met by 2030. The purpose of these targets is to transform the world, and in order to make them feasible and adhered to, they have been divided into 17 categories and are called Sustainable Development Goals (SDGs): (1) No Poverty, (2) Zero Hunger, (3) Good Health and Well-being, (4) Quality Education, (5) Gender Equality, (6) Clean Water and Sanitation, (7) Affordable and Clean Energy, (8) Decent Work and Economic Growth, (9) Industry, Innovation and Infrastructure, (10) Reducing Inequality, (11) Sustainable Cities and Communities, (12) Responsible Consumption and Production, (13) Climate Action, (14) Life Below Water, (15) Life On Land, (16) Peace, Justice and Strong Institutions, and (17) Partnerships for the Goals. The SDGs were created and act to eradicate poverty, protect the climate and the environment, and ensure that all beings have peace and prosperity. The human being is also responsible for the achievement of the SDGs; the main source of electric energy waste analyzed in their study refers to the behavior of the occupants of the studied building [38].

### 3. Materials and Methods

#### 3.1. Systematic Literature Review

As a research method, a systematic and bibliometric literature review was conducted on the topic of digital transformation and its relationship to the topic of sustainability, using the PRISMA 2020 and inclusion and exclusion criteria from [39]. Following the criteria of the framework and seeking to answer the research question of “What is the degree of contribution of DT-enabling technologies to the sustainability areas of companies?”, the constructs “Digital Transformation” and “Sustainability” were selected. From these constructs, the search string (“Digital Transformation” and “Sustainability”) was executed in the academic databases Scopus, Web of Science (WoS), Emerald, and ScienceDirect.

Seeking to refine the search in the bases, the search was restricted to articles published in academic journals and within a 5-year period (2016 through 2021) to ensure there were only the most recently published articles on the proposed topic.

The first search of the databases resulted in a total of 947 filtered articles, of which 249 were obtained from WoS, 322 from Scopus, 299 from Emerald, and 77 from ScienceDirect. The 947 articles were grouped into categories according to the inclusion and exclusion criteria, formatted following the framework by [39], shown in Table 1.

**Table 1.** Inclusion and exclusion criteria included in the SLR.

	Explanation
SER	Papers that do not have the constructs in the title, abstract, or keywords.
WF	Papers do have the constructs but without full text to be accessed.
NR	Papers do not have a relation to the topic, or they are comments, revisions, summaries, or proceedings.
LR	Exclude papers where the topic of sustainability appears but that are not related to digital transformation.
PR	Include papers where digital transformation is the main topic but is not related to sustainability. The constructs are used as support to cover other topics. There are the constructs but not as the focus.
CR	Include papers where the constructs are related to the topic and they are part of the focus.

In the final distribution using the criteria described above, 689 articles went into the SER category, 8 articles into WF, 61 into NR, 8 into LR, and 111 into PR, and finally classified into CR, there were 70 articles, which were used for SLR analysis and final report. Regarding the growth rate of publications on the subject, the results show that, in 2017, the articles that related DT technologies to the theme of sustainability were still discrete (2 publications) and that throughout the years 2018 (7 publications), 2019 (14 publications), and 2020 (36 publications), they tended to grow, noting that in 2021 (12 publications), the research was closed in August 2021.

When evaluating the 70 selected publications, Sustainability magazine stands out with a concentration of 26 publications. Regarding the publications, the analysis in the WoS academic database shows that sustainability-related DT presents a higher concentration in the following areas: Green Sustainable Science Technology (70), followed by Environmental Science (61), Environmental Studies (56), and Business (42); only then do we see categories such as: Management (24), Computer Science (19), Economics (14), Engineering Industrial (14), and Education (12).

### 3.2. Digital Enabling Technologies of DT for Company Sustainability

Table 2 presents the list of 70 articles organized by DT-enabling digital technology from the SLR.

**Table 2.** DT-enabling technologies indicated for company sustainability.

#	Technology	Articles	Citations
1	Big Data and Analytics	[7,8,11,12,20,23,27,30,34,35,40–79]	50
2	IoT (Internet of Things)	[7,11,12,20–23,25,27,30,34,35,40–48,50–54,56–62,64,65,67,68,70–88]	56
3	AI (Artificial Intelligence)	[7,20,23,25,27,30,35,40,46,48,51,53,54,58–60,62–65,67,68,70,71,74–77,79,82,86,87,89–93]	33
4	Social Media	[27,57,61,68,70]	5
5	Cloud Computing	[7,12,20,23,27,30,42,48,50,51,54,58,59,62–65,67,70–73,83]	23
6	APIs	[21,65]	2
7	Blockchain	[23,58,60,62,70,74,75,85–88]	11
8	RFID	[83,88]	2
9	GPS	[35,54,61,85,88]	5
10	CPS (Cyber-Physical System)	[12,20,24,25,30,40,45–47,50,53,54,60,63,64,73,75,80,91]	19
11	AR (Augmented Reality)	[12,25,34,35,48,53,58–60,64,73,83,85]	13
12	3D Printer (Additive Manufacturing)	[12,25,35,42,50,53,56,58,60,62,64,72,73,83,85,93]	16
13	Robotics	[7,20,35,42,50,53,58,70,72,83,92]	11
14	Smart Materials	[35,68,85]	3
15	VR (Virtual Reality)	[12,49,53,70,72]	5
16	WEB 4.0	[49]	1
17	ML (Machine Learning)	[7,11,30,53,60,67,73,75,82,84]	10
18	Agility	[94]	1
19	5G Mobile	[25]	1
	TOTAL		267

To select the impacting technologies, among the 19 cited by the authors, we resorted to the author [95], according to whom the ABC Curve concept is widely used in several

companies, in various applications [96], for information classification. In these cases, the most relevant items are classified as A, the medium relevant items are classified as B, and the low relevant items as C.

The percentages for classification do not follow a fixed mathematical rule for all cases, with various cut-off values for each of the classification ranges (A, B, and C) [97]. Given this lack of uniformity and the absence of references on the subject in the literature, the following classification criteria were used in this study: 73% of the citations made up the A items, 17% the B items, and 10% the C items. Table 3 shows the classification of the digital technologies cited, which led to a result of five most relevant technologies, classified as A, representing 73% of the total 267 citations in the researched and selected articles.

**Table 3.** ABC Curve of the most impacting digital technologies for sustainability.

Technology	Quantity Citations	% Citations	% Accumulated	Technology Classification	Digital Technology
2	56	20%	20%	A	IoT (Internet of Things)
1	50	19%	39%	A	Big Data and Analytics
3	33	12%	51%	A	AI (Artificial Intelligence)
5	23	9%	60%	A	Cloud Computing
10	19	7%	67%	A	CPS (Cyber-Physical Systems)
12	17	6%	73%	A	3D Printer (Additive Manufacturing)
13	13	5%	78%	B	Robotics
11	11	4%	82%	B	AR (Augmented Reality)
7	10	4%	86%	B	Blockchain
17	10	4%	90%	B	ML (Machine Learning)
4	6	2%	92%	C	Social Media
15	6	1%	93%	C	VR (Virtual Reality)
9	4	1%	94%	C	GPS
6	2	1%	95%	C	APIs
8	2	1%	96%	C	RFID
14	1	1%	97%	C	Intelligent Material
16	1	1%	98%	C	WEB 4.0
18	1	1%	99%	C	Agility
19	1	1%	100%	C	5G Mobile

Therefore, for the purposes of this work and based on the selection criteria adopted, the enabling technologies considered relevant were those that were ranked by the ABC Curve. These were the enabling technologies that were considered in measuring the degree to which DT contributes to the sustainability of companies.

- (a) IoT (Internet of Things): these are the objects that combine information and communication without human interference. The concept of IoT service is the orchestration of a common service management network of separate systems, applications, and sensors [22].
- (b) Big Data and Analytics: represents information assets characterized by high volume, speed, and variety that require specific technology and analytical methods for their transformation into value; it is generally the term used for the data set that is so large or complex that traditional data processing applications are inadequate [20].
- (c) AI (Artificial Intelligence): artificial intelligence feeds the information used in chatbots (programmed response robots) along with machine learning techniques which allow to understand natural language and interact with users in personalized way [90].

- (d) Cloud Computing: multidirectional communication between production processes and products [86].
- (e) CPS (Cyber-Physical Systems): sophisticated ecosystem-based engineering that integrates virtual and physical environments [91].
- (f) 3D Printer (Additive Manufacturing): three-dimensional printing; changes the value proposition in business in manufacturing companies [60].

### 3.3. Analysis of Selected Articles in SLR

Although the SLR resulted in 70 articles with varied indications of DT technologies related to the theme of sustainability (Table 2), the authors defined the strategy of considering for analysis one article that more specifically addresses each of the technologies and articles that contain the largest number of technologies from the six most relevant ones, thus leaving 38 articles for the final SLR report, analyzed below according to Table A1.

### 3.4. Degree of Contribution of DT-Enabling Technologies to Sustainability

To determine the degree of contribution of DT-enabling technologies to sustainability, we used the structure developed by [10] in their study on competitiveness that adopted a framework composed of “elements” and “components” to define the contribution degree of competitiveness of companies in the automotive sector. Each element can be analyzed in four degrees—equivalent to four descriptive items attached. These items describe competitive strategies, as the example illustrated in Table 4.

**Table 4.** Example of an element and statement.

Element	Affirmation
Design—important role in designing products	New product design development for customers

Using the mechanics from [10], the statements in this research were designed to measure a degree of contribution by assigning four levels ranging from N0 to N3. The statements correspond to some action, ranging from absent to complete incorporation, as illustrated in Table 5.

**Table 5.** Contribution level.

Level	Classification
N0	Absent
N1	Low Incorporation
N2	Medium Incorporation
N3	Complete Incorporation

This way and using the proposal of [10], the affirmations presented in Table 6 were defined in this study regarding the 6 most relevant enabling digital technologies in the DT process, which were the most cited in the bibliographic study carried out (Table 3). The statements related to the technologies describe each company’s scenario regarding the application of each of the six technologies. In this way, it is possible to collect through the answers the contribution level of each technology according to Table 6.

**Table 6.** Dimensions and affirmations.

Dimension	Affirmation
a. IoT (Internet of Things)	(a.1) IoT is not used in any capacity at our company
	(a.2) IoT is used only for capturing and storing data
	(a.3) IoT is used for capturing and storing data, and interacts with core business functionalities
	(a.4) IoT is used for capturing and storing data, interacts with core business functionalities, and is positively related to environmental issues
b. Big Data and Analytics	(b.1) Big Data and Analytics is not used in any capacity at our company
	(b.2) Big Data and Analytics is used in an incipient form, without generating value for the company
	(b.3) Big Data and Analytics provides predictive insights for results, drives real-time operational decisions and reinvents business processes
	(b.4) Big Data and Analytics provides predictive insights for results, drives real-time operational decisions and reinvents business processes, and is positively related to environmental issues
c. AI (Artificial Intelligence)	(c.1) Artificial Intelligence is not used in any effective capacity at our company
	(c.2) Artificial Intelligence is integrated in the business model at peripheral activities
	(c.3) Artificial Intelligence is integrated in the business model at both peripheral and core activities
	(c.4) Artificial Intelligence is integrated in the business model at both peripheral and core activities, and is positively related to environmental issues
d. Cloud Computing	(d.1) Cloud computing is not used in any capacity at our company
	(d.2) Cloud computing is integrated into the business model at peripheral activities
	(d.3) Cloud computing is integrated into the business model at both peripheral and core activities
	(d.4) Cloud computing is integrated into the business model at both peripheral and core activities and is positively related to environmental issues
e. CPS (Cyber-Physical Systems)	(e.1) CPS are not used in any capacity at our company
	(e.2) CPS are used in an embryonic or non-central aspect of the business model
	(e.3) CPS are integrated at the core of the business model
	(e.4) CPS are integrated at the core of the business model and is positively related to environmental issues
f. 3D Printer (Design, Engineering, Operations of Construction, etc.)	(f.1) CPS are not used in any capacity at our company
	(f.2) CPS are used in an embryonic or non-central aspect of the business model
	(f.3) CPS are integrated at the core of the business model
	(f.4) CPS are integrated at the core of the business model and is positively related to environmental issues

Therefore, the authors considered N0 when the company did not use the technology; N1 when the company used it in a very primary way or only in some processes; N2 when the company used the technology widely and had innovative results in processes or business models; N3 when the technology was used strategically and was aiming for sustainability. It is important to note that the contribution level is associated with a score for each statement; that is, each statement chosen by the respondent corresponds to a score for calculating the degree of contribution of DT-enabling technologies to sustainability. Table 7 shows the scoring and adapted ranking described from Table 5 in regards to complete incorporation.

**Table 7.** Score definition.

Level	Points	Classification	Description
N0	1	Absent	There is no use of this technology. It is still being tested.
N1	2	Low Incorporation	It is a known technology. Used in a few processes.
N2	3	Medium Incorporation	Wide use of this technology. Important results.
N3	4	Complete Incorporation	Completely used to support sustainability. Strategic perspective.

Through measurement scales, it is possible to transform opinions and attitudes, qualitative facts into quantitative facts, for data analysis through statistical processes [98]. The group selected for study consisted of 3 respondents from each company, one of the 3 pulp and paper manufacturing companies participating in the field research. The respondents were from different roles such as IT Coordinator, Business Partner for Sustainability, Head of Tech Innovation, Innovation Manager, IT Manager, and Sustainability Analyst and Diversity leader. The choice of the unit of analysis for this study was related to companies that have production processes that impact the environment. The first company was one of the largest packaging paper producers and exporters of hardwood, softwood, and fluff pulp. The second was a company that invests in different segments, including paper. The third was a company that is one of the global players in the development of products made from planted eucalyptus forests and one of the largest vertically integrated producers of eucalyptus pulp and paper. The GEO initiative “Earth Observations in Service of Agenda 2030” issued a report presenting a series of studies with forest monitoring data and water quality monitoring, and a forest management system powered by Big Earth Data is under development [55].

As part of the strategy to mitigate social desirability, the questionnaire form was forwarded to the selected respondent group: one employee who works in the technology area, one employee who works in the sustainability area, and one employee who works in the innovation area. The questionnaire was composed of two sections: Section 1 collected data from the respondent so that the analysis could be segmented, if necessary; Section 2 had 4 statements of actions for each element (technology), in which the respondent had to identify only one that was related to the scenario of the company in which he/she works.

Through simulations with the scales and the mathematical operation present in the mechanics of [10], the scale and the mathematical operation were adjusted and adapted for this study in order to perform the calculation with assertiveness. A range of scores from 3 (minimum) to 12 (maximum) points collected from the answers suggests the possible degree of contribution of each technology. In view of the simulations performed, it was necessary to create, determine, and classify each degree of contribution: from 3 to 5—this technology is not relevant in this company; from 6 to 9—this technology is important in this company; from 10 to 12—this technology is relevant in this company, illustrated in Table 8.

**Table 8.** Classification.

Degree of Contribution	Classification
03–05	Not relevant
06–09	Important
10–12	Relevant

The pre-test was conducted with 3 respondents: (1) director of consulting in innovation, (2) Ph.D. professor in sustainability, and (3) manager of IT projects. Contributions and suggestions regarding the arrangement of check boxes in the identification questions were taken into account and adjusted in the questionnaire.

#### 4. Analysis and Results

The overall analysis concluded that the IoT (Internet of Things) is used for capturing and storing data (three answers) and for capturing and storing data and interacts with core business functionalities (three answers), while big data and analytics has the highest number of responses (four answers) when it is used in an incipient way, without generating value for the company.

Unfortunately, AI (Artificial Intelligence) is still not used in any effective way (six answers); on the other hand, cloud computing presented the most answers as it is integrated in the business model at both peripheral and core activities (four answers) and is integrated in the business model at both peripheral and core activities and is positively related to sustainability issues (three answers).

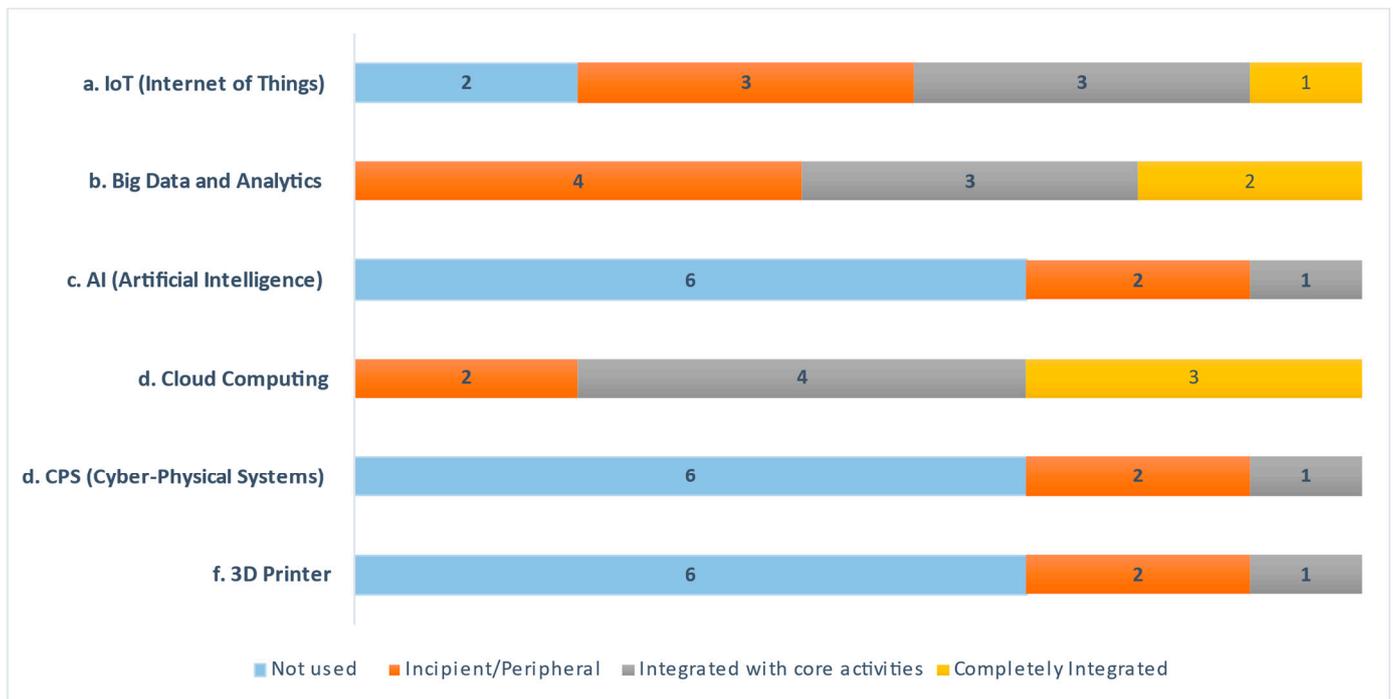
Although most answers (six answers) stated that CPS (Cyber-Physical Systems) are not used in any capacity at the company, two responses stated the use of CPS is integrated at the core of the business model; when we asked about 3D printers, only one answer stated that 3D printers reduce costs and waste and provide flexibility and innovation to business activities, and for the most part (seven answers), 3D printers are not used in any capacity at the company.

Figure 1 presents the results of the answers from the field survey in the three Brazilian pulp and paper companies. Numbers in the figure represent the number of respondents for each technology, divided by colors representing the degree of utilization in the examined companies.

The separate analysis of companies presents the following results (Table 9):

- In company 1, cloud computing, big data and analytics, and the IoT (Internet of Things) are important technologies for DT in sustainability.
- In company 2, beyond the technologies of cloud computing, big data and analytics, and the IoT (Internet of Things), CPS (cyber-physical systems) are also considered an important technology for DT in sustainability.
- In company 3, cloud computing is the most relevant in strategy for DT in sustainability, and big data and analytics, the IoT (Internet of Things), and AI (Artificial Intelligence) are relevant for DT in sustainability.

The data were consolidated by using the central tendency measure (mean) of each company's degree of contribution. In the results presented in Table 10, it is observed that company 3 has a higher score in the degree of contribution of the enabling technologies (score 7.17) compared to company 2 (score 6.33) and company 1 (score 5.50).



**Figure 1.** Overall analysis.

**Table 9.** Analysis by company.

Technology	Company	Degree	Classification
IoT (Internet of Things)	01, 02	7	Important
	03	8	Important
Big Data and Analytics	01, 02	8	Important
	03	9	Important
AI (Artificial Intelligence)	01	3	Not relevant
	02	4	Not relevant
	03	6	Important
Cloud Computing	01, 02	9	Important
	03	10	Relevant
CPS (Cyber-Physical Systems)	01	3	Not relevant
	02	6	Important
	03	5	Not relevant
3D Printer	01	3	Not relevant
	02	4	Not relevant
	03	5	Not relevant

Digital transformation is a strategic factor for the company, yet there is no common practice to measure the degree of contribution or relevance of digital technologies when applied to sustainability. The identification of a set of enabling technologies in the literature was the first and main step to propose a logic to measure the degree of contribution of these technologies in companies that have a sustainability area.

This article defined a practical way to assess DT-enabling technologies and defined their classifications as not relevant, important, and relevant in pulp and paper manufacturing companies that have a sustainability area, thus determining their degree of contribution to the sustainability of the company.

**Table 10.** Average by technology and average and overall average by company.

Technology	Company 01	Company 02	Company 03	Score	Classification
IoT (Internet of Things)	7	7	8	7	Important
Big Data and Analytics	8	8	9	8	Important
AI (Artificial Intelligence)	3	4	6	4	Not relevant
Cloud Computing	9	9	10	9	Important
CPS (Cyber-Physical Systems)	3	6	5	5	Not relevant
3D Printer	3	4	5	4	Not relevant
Total Score	5.50	6.33	7.17		

In the consolidated analysis of the six digital technologies, it was observed that:

- The important technologies for the companies assessed in the subject of DT and sustainability are: IoT (Internet of Things), big data and analytics, and cloud computing.
- The technologies that are not relevant for these companies on the subject of DT and sustainability are: AI (Artificial Intelligence), CPS (Cyber-Physical Systems), and 3D printers.
- None of the six technologies in the consolidation reached the degree of “relevant”.

It must be registered that this is a snapshot of this moment in time, and these results can help companies come up with strategies and plans for a different positioning of these technologies. Table 11 shows the individual analysis of each of the six technologies.

**Table 11.** Classification by company.

Technology	Company 1	Classification	Company 2	Classification	Company 3	Classification
IoT (Internet of Things)	7	Important	7	Important	8	Important
Big Data and Analytics	8	Important	8	Important	9	Important
AI (Artificial Intelligence)	3	Not relevant	3	Not relevant	6	Important
Cloud Computing	9	Important	10	Relevant	10	Relevant
CPS (Cyber-Physical Systems)	3	Not relevant	6	Important	5	Not Relevant
3D Printer	3	Not relevant	4	Not relevant	5	Not relevant

- IoT (Internet of Things) has a contribution grade between 7 and 8, with an “important” rating in the three companies surveyed;
- Big Data and Analytics has a contribution grade between 8 and 9, and the “important” rating was seen in the three companies surveyed;
- AI (Artificial Intelligence) has a contribution grade of 3 and a “not relevant” classification in company 1 and company 2, respectively; it has a contribution grade of 6 and an “important” classification in company 3;
- Cloud Computing has a contribution grade between 9 and 10, and a “relevant” rating was found in the three companies surveyed, being the only technology that scored a grade of 10 “relevant” in company 3;
- CPS (Cyber-Physical Systems) has contribution grade 3 and “not relevant” classification in company 1; it has contribution grade 6 and “important” classification in company 2; it has contribution grade 5 and “not relevant” classification in company 3;

- 3D Printer was rated as “not relevant” with a contribution grade of 3, 4, and 5 for company 1, company 2, and company 3, respectively.

The IoT (Internet of Things) and CPS (Cyber-Physical Systems) deserve additional comments. Both technologies have the same concept but with different views from outside and inside with the IoT (Internet of Things) from outside with thousands of devices capturing data such as cameras monitoring customer behaviors and CPS (Cyber-Physical Systems) from inside with devices and types of equipment contributing such as high-tech assembly lines, for example, the embedded systems of equipment that perform specific and dedicated functions. Even though they represent the same reality, it is possible to notice differences when comparing answers from the three companies.

## 5. Discussion

The analysis of the results presented in Table 10 showed that the Brazilian pulp and paper companies that were surveyed are still in the process of growth when we calculated the degree of contribution of the technologies in the DT process to their sustainability areas. Only the digital cloud computing technology appears as relevant in one of the companies, which differs from our theoretical framework constituted by the literature and studies from other countries, which suggests the need for further studies on companies from other branches in the Brazilian market.

For the purpose of comparison of results published in the literature on the subject, authors [83] analyzed the 17 SDGs and the relationship with the definition of I4.0. As a result of the analysis, the IoT, cloud computing, and 3D printer technologies (also DT enablers) are applied for the achievement of the SDGs in sustainability, according to Table 12.

**Table 12.** Technologies and the SDGs.

Technology	SDGs	Benefits
IoT (Internet of Things)	3, 5, 7, 8, 9, 11, 12, 17	Efficient processes, data sharing between robots, increased production capacity and innovation levels.
Cloud Computing		Process innovation and expansion.
CPS (Cyber-Physical Systems)		Collaboration and resource consumption reduction.

In the literature, it was found that innovation made it possible to highlight economic and environmental aspects and gains related to SDGs 9, 12, and 15 [99]. In I4.0, a great chance for alignment to the SDGs can be offered with continuous DT in industrial development [61]. DT will have a positive effect on corporate social responsibility [93].

According to [100], Brazil still has a weak sanitary infrastructure to treat waste, solid garbage, sewage, and cooking oil. Therefore, sustainable development is still far from Brazilian homes in some regions. Nevertheless, some actions meet the 2030 SDGs agenda aimed at economic growth. The research carried out by these authors in Brazil and Portugal presents the following priorities: SDG9 is the priority for both countries in the economic dimension. It associates clean production that affects the survival of companies in general. SDG17 is a priority for countries in the social dimension, and here it emphasizes the role of AI-driven DT to connect people and provide data. The results presented in the environmental dimension in Portugal indicate SDG14 (Life Below Water) and in Brazil show SDG15 (Life on Earth), where the adoption of AI-driven DT can overcome the cultural and technical barriers existing today. As for the preference of AI-based DT, it is highly manifested by digital education national platforms to revolutionize different disciplines to meet the SDGs, in part because of its wide-reaching populations.

In I4.0, there is a chance for alignment to the SDGs with continuous DT in industrial development [61]. According to [101], I4.0 has many relationships with sustainability

through the Triple Bottom Line that need to be investigated and put into practice. The authors disclose that the interaction of technology bases and potentials within sustainability needs to be studied. Currently, the literature does not address whether the I4.0 technologies help sustainable manufacturing. There is no in-depth study of the results in products, processes, and systems. The authors indicate the need for future research on sustainable manufacturing through I4.0 technologies. Studies [102,103] developed a model to assess the influence of Industry 4.0 technologies on sustainability. The leading technologies influencing sustainable development are AI, cyber-physical systems, sensors, and data. Interestingly, these technologies positively impact the economy but negatively affect society. On the other hand, robots, cloud computing, and system integration technologies negatively impact job creation. The IoT was ranked as one of the most relevant technologies with a high impact on sustainability.

I4.0 technologies (also DT enablers) contribute to forest management, biodiversity, sustainable promotion of industries, scientific research and innovation, infrastructure upgrading, and sustainable energy efficiency [62].

## 6. Conclusions

To achieve the SDGs, countries, especially emerging ones such as Brazil, need to develop their technologies and businesses and improve the results that relate to sustainability.

The contribution of this study to the academic field includes the systematic review of the literature on digital transformation and sustainability. It resulted in Table A1, which shows the authors' perspectives regarding this topic, including goals, results, and comments regarding each selected academic article. For companies, it is possible to replicate the field research and identify the degree of DT-enabling technologies for sustainability within the company and develop an analysis and action plan to improve these production processes concerning sustainability. This research has some limitations that create avenues for future research. It focuses on digital transformation and sustainability, but there is a critical aspect to be addressed in the future: social development as an outcome of digital transformation technology. An important point to be discussed is the relationship with the SDGs in the UN 2030 agenda, which is not present in much of the researched literature, indicating a suggestion for future studies.

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## Appendix A

**Table A1.** Report on the analysis of selected articles from the SLR.

Author	Goal	Results	Comments
[7] Jones and Wynn	To analyze market-leading companies regarding the use of DT technologies to provide sustainability in their sectors.	The article concludes that the current sustainability objectives of technology companies are moved both by commercial reality and for altruistic reasons and that support and promotion of circular economy can offer the best opportunity for digital technologies to impact sustainable development significantly.	Concerning digital technologies to provide sustainability, cloud computing, AI, big data and analytics, intelligent sensors, adaptive robotics, and machine learning leverage the evolution of traditional factories to become efficient and sustainable smart factories.
[20] Wolfert et al.	To analyze the use of big data in factories and agricultural business transformation.	This analysis showed that the big data utilization started influencing the entire food supply chain, including raw materials, support to agricultural operations, and deciding on real-time and business processes redesign.	Big data's improvements are helping farmers to improve their business profitability and effectiveness, making the agribusiness increasingly sustainable.
[21] Diez et al.	The aim of the article is to study digital transformation technologies and sustainability for the promotion of smart cities.	The study proposed a validation framework for smart-city projects to create an interoperability certificate, focusing on IoT technology.	Most smart cities have IoT devices as their main tool for data interoperability, through their sensors and for homogeneously storing data. Synchronism with some global Application Programming Interfaces (APIs) for stored data validation was verified. The authors concluded that due to the maturity reached by IoT technologies and their widespread presence, it is a fundamental aspect to develop urban environments.
[22] Hu, Chohan, and Liu	The study investigated the influence of factors in the intention of using IoT in public services by citizens.	The results of the studies show that the success of public services with IoT can be measured in the value perceived by citizens. The IoT technology was 59% positive.	This study contributed to the identification of actors related to public involvement with the IoT service, along with the description of the positive role of sustainable digital affinity with society.

Table A1. Cont.

Author	Goal	Results	Comments
[23] Putthiwat, Kamonchanok, and Pongsa	To research and develop digital transformation factors that can impact logistics service providers in Thailand, including the sustainability perspective.	Adopting perspectives from DT as part of a strategic transformation, companies can increase their competitive advantages and become sustainable.	DT in logistics and supply chain management represents changes in the value created by digital technologies. It means adapting strategies and processes and adaptation of facilitators, such as innovation and leadership to accomplish goals, as an increase in agility, higher productivity, and a more customer-centric approach and supply chain. Included technologies are web, cloud computing, sensors, analytics (big data), machine learning, blockchain technology, and IoT, which improve supply chain networks' vertical and horizontal alignment.
[24] Hidayatno, Desttyanto, and Hulu	The research aimed to discover the systemic impact of the development and implementation of digital technologies for sustainable energy transition.	Proposal of a causal loop diagram, conceptual model, which would help better understand the variables that allow measuring the impact of Industry 4.0 technologies and quantitatively measure sustainable industrial energy in Indonesia.	Several surveys have attempted to quantitatively measure or predict the impact of Industry 4.0 technologies for sustainable industry energy. Authors summarized their research into two significant challenges, the first concerning renewable energies, which still contribute a 19.2% share of the Global Final Energy Consumption in 2016, and the second, energy efficiency. The study showed that the adoption of digital technologies of big data analytics, cloud computing, AR, AM, and others positively impacts energy efficiency.
[25] Brunetti et al.	The article through interviews analyzes the resistance to the implementation of digital transformation technologies in companies in the Tyrol Veneto region.	The authors for each challenge found proposed strategies that can help in the implementation of digital technologies.	Resistance is mainly related to digital culture or the implementation of new technologies, infrastructure, and technologies such as the Internet and stable networks for the application of IoT and AI associated with big data and analytics, among others.
[27] Feroz, Zo, and Chiravuri	Conduct a literature review for mapping DT in the scope of sustainability.	Digital technologies generate positive improvements for industry and society, as well as improvement of the environment. It is important to note that these technologies are not useful for achieving sustainability goals on their own without organizing the resources to use them.	Companies now rely on digital technologies such as AI, IoT, and big data and analytics to carry out sustainable business practices that involve reducing carbon emissions and minimizing other waste to the environment. Blockchain is considered a tool with enormous potential to achieve sustainability in business and industrial practices as it offers resources to extend the product life cycle, maximize the use of resources, and reduce carbon emissions, contributing to sustainability.

Table A1. Cont.

Author	Goal	Results	Comments
[30] Birkel et al.	The article proposes a framework of risks in the context of Industry 4.0 related to the Triple Bottom Line of sustainability.	This article discusses the framework based on the existing literature. Then, it proposes managerial and theoretical implications and suggests paths for future research.	The greatest concern regarding the use of technologies was AI due to its power in decision making and the possible loss of human control over them. Other risks highlighted: job loss because AI-powered technology is attributed to analyses carried out in big data, IoT, and others, making the workforce increasingly specialized. It can be seen as a sustainability risk.
[35] Akyazi et al.	To analyze the technologies in the European construction sector that is in the process of recovery.	It concluded that the European civil engineering sector needs to upgrade the skills of its workforce so that it can grow steadily and be a competitive industry, as it used to be in the past.	The development of smart digital technologies (AI, ML, big data and analytics, robotics, IoT, 3D printer, and others) facilitates a new phase of automation for this industry. Some of the innovations in construction are Building Information Modeling (BIM), sensor systems, smart materials, drones, etc. The results are reflected in the reduction of construction cost due to zero waste (sustainability).
[40] Waibel et al.	To analyze the social and environmental impact of digital transformation technologies.	This analysis showed that technology made maintenance easier, and from the environmental perspective, impacts tend to be reduced since technology promotes higher sustainability.	Authors state that big data, cloud, and IoT have been integrating systems that facilitate maintenance by people around the globe. In addition, those technologies improve data availability and predictability, contributing to sustainability and anticipating planning regarding the environment.
[41] Kenett, Zonnenshain, and Fortuna	To review data analytics and how it provides support to sustainable and advanced manufacturing.	Since Data Science is a multidisciplinary science, authors proposed a road map for analysis and techniques for sustainable advanced manufacturing.	Big data and analytics technology has great potential to deepen the understanding of phenomena that range from physical and biological to human and behavioral systems. Furthermore, with the union of mathematical algorithms, big data and analytics technology combined with IoT promotes sustainable manufacturing which means manufacturing processes with lower energy consumption and greater efficiency and real-time resource consumption monitoring.
[42] Luthra and Mangla	To demonstrate the challenges faced in implementing I4.0 (DT) technologies in the context of sustainability.	Using the AHP method, the authors identified four dimensions of changes that the introduction of digital technologies causes and challenges it brings. The focus of the study was the supply chains of Indian manufacturing companies.	IoT is a challenge because of the lack of global standards and data sharing protocols and poor Internet connectivity. Due to the low quality of the data, big data and analytics can cause huge security problems. These risks are also incurred in relation to the sustainability of the studied companies.

Table A1. Cont.

Author	Goal	Results	Comments
[43] Bressanelli et al.	To analyze if digital technology supports the circular economy paradigm.	Results from the proposed framework and applied case study show that digital transformation technologies can support the circular economy.	IoT technology transforms standalone products into intelligent and connected ones, and through it, companies can perform real-time monitoring of them. Big data and analytics can positively improve the management for the benefit of CE. CE paradigms promote sustainability.
[45] Dakhnovich, Moskvina, and Zeghzda	The article shows industrial safety challenges of Sustainable Industrial Control Systems (ICS) for Digital Transformation (DT).	It proposed an approach based on “garlic” routing principles to secure communications and provide a stable manufacturing process due to information failures, availability, and integrity between different segments.	The main challenge in providing security in digital manufacturing is keeping production sustainable by using IoT and other digital technologies. However, the authors raised the concern that not all companies can use big data systems with the IoT, placing the information directly in cloud computing, causing risks regarding information leakage.
[48] Savastano et al.	The goal was to verify the bibliographic database, providing a systematic literature review regarding Digital Transformation (DT).	Despite the concept and proposed technologies being new, authors concluded that they have accelerated industries and that there are also signs of growth in academic research.	Results show that the most widespread technologies in DT are: 3D printer, IoT, robotics, big data, cloud computing, and CAD tools. It shows that additive manufacturing uses most of these technologies, and it comes from smart factories. Additionally, sustainability is a motivator for adopting smart factories.
[50] Braccini and Margherita	To explore the industry organizational sustainability based on the TBL (Triple Bottom Line).	Results show that I4.0 technologies support the three sustainability dimensions (social, economic, and environmental).	The case study showed an increase in the balance sheet, a reduction in production lead time and energy consumption, and increased product quality and tracking of the production process. The technologies were CAD tools, 3D printer, IoT, big data and analytics, and robotics.
[51] Wang, Xu, and Ren	The article proposes the introduction of smart factory techniques for coal mining in China, called smart mining.	The article verifies that some problems still cannot be solved unless some technologies get better. However, the combined use of the new Industry 4.0 technologies already solves some of the problems encountered by miners in China.	The proposal was for coal mines to carry out the acquisition of information and fusion technology through IoT, automation, AI, big data and analytics, and cloud computing as a high-precision security platform. It verifies the mines are changing, allowing quick access in case of accidents, including through on-site sensors. The use of 3D printers aids in the geographic mapping of mines, and these analyses can evolve into unmanned mining through the use of robots and autonomous machines based on AI.

Table A1. Cont.

Author	Goal	Results	Comments
[53] Ávila-Gutiérrez et al.	The article proposes a framework for sustainability in line with the objectives of the 2020 Agenda for Sustainable Development.	The research presented a framework that supports the entire life cycle of systems and standardizes the circular economy (CE) as a paradigm of sustainability.	The Circular Economy (CE) is identified as a paradigm of sustainability and is characterized by its teleological, epistemological, ontological, axiological, and methodological aspects. The synergy of implementing sustainability through the CE paradigm in conjunction with Digital Transformation (DTY) allows for the use of a wide range of efficient techniques and tools. The article mentions technologies such as: IoT, CPS, robotics, AI, VR, AR, ML, and 3D printer.
[54] Pencarelli	Article aim is to analyze how tourism is changing with digital technology use.	The article found that Tourism 4.0 or smart tourism is being created by incorporating digital technologies and changing tourists' experiences.	Smart tourism, as it is also called, aims at sustainable use and is based on technologies such as IoT, connectivity, AR, VR, and AI. A new tourist experience can be offered in pre-sale through Web 4.0, and all digital networking platforms and their experiences can capture tourists' tastes and desires. Smart tourism is distinguished by scientific and technological innovations that are oriented toward people and sustainability.
[56] Kunkel and Matthes	The aim of the article is to study the risks of employability of digital technologies in the territory of Sub-Saharan Africa and the risks involved in the adoption of these technologies.	The analysis showed that policies express a wide range of vague expectations with more focus on the positive indirect impacts of the use of ICTs, the so-called green ICTs, for example, to increase efficiency and resource management, rather than the direct negative impacts of ICTs, such as electricity consumption.	There is a growth in energy use due to the creation of data centers and servers. On the other hand, with regard to resource efficiency, the study pointed out that it is possible that 3D printers have been increasing their efficiency in industry productions, with big data and analytics technology being identified as the main technology for the production of renewable energy.
[58] Ávila-Gutiérrez et al.	Proposed a circular business model (CE) based on Eco-Holonic Architecture to manage the complexity of integrating circular economy principles.	The study showed that the main enabling technologies for digital transformation in business are CPS to monitor and control it in real time, big data and analytics using AI for intelligent manufacturing creation, and use of robotics, VR, cloud computing, and LM, among others.	The objective of sustainability and CE is to naturalize technical systems from events that occur in the natural world. The main challenge for this approach is to bring the dynamics of natural operation (of natural ecosystems) to the industrial sector so that the rational use of natural resources occurs according to the rhythm of renewal, respect, and cooperation with nature.

Table A1. Cont.

Author	Goal	Results	Comments
[59] Ng and Ghobakhloo	The article reports the ways in which Industry 4.0 offers opportunities related to energy sustainability and how this happens.	The results indicate that there are sophisticated relationships of precedence between numerous energy sustainability functions of Industry 4.0.	It points out that intelligent automation, IoT, and CPPS can accelerate the deployment of sustainable energy in the manufacturing environment. In the energy transformation sector, the implementation of smart grids offers better energy management capabilities, and monitoring equipment and sensors offer the opportunity for production efficiency. AI supports energy sustainability through deep mining of existing data and decision making with big data and analytics technology.
[60] Godina et al.	The authors studied digital transformation technologies in the context of additive manufacturing which is a central element of the fourth industrial revolution.	The authors concluded that additive manufacturing technology or smart factories, when combined with other technology concepts from Industry 4.0, will revolutionize the production scenario.	They presented the benefits of IoT associated with the use of big data and analytics technology, allowing the monitoring and optimization of processes in real time. Smart factories are strongly supported by digital transformation technologies which are: AI, robotics, IoT, and big data and analytics. In this way, active manufacturing is not limited to the development of a new design, as it offers products with better performance, less waste, and adaptable production.
[61] Beier et al.	The objective is a literature review to verify the alignment of digital transformation technologies with sustainable development.	Industry 4.0 is not a single technology but a socio-technical concept in which technological, social, and organizational aspects interact. Effects of individual aspects do not necessarily allow conclusions to be drawn about the overall impacts on the overall sustainability system concept.	Big data and analytics have helped transform large amounts of raw data into useful information and technically support automations, making them increasingly sustainable. Through machine networks, Industry 4.0 increasingly allows for interconnectivity, with the use of RFID, cloud computing, and IoT. Systemic studies in a value chain located in a wide system become necessary to reliably estimate the real implications for the sustainability of the industrial concept.
[62] Bai et al.	In a case study, the authors verified whether Industry 4.0 technologies, such as AI, AR, autonomous robots, big data and analytics, blockchain, cloud computing, cyber security, IoT, nanotechnology, RFID, sensors, and simulation, could be classified as sustainable from the objectives of the SDGs and for different sectors.	The results show that despite being treated as a group of Industry 4.0 technologies, they are observed with greater granularity by each sector. Studies show that there are so-called trade-offs in some impacts, which does not allow for an exact measurement.	The authors argued that companies need to consider the contribution of digital technologies to sustainability. For example, nanotechnology is more sustainable in the automotive sector. IoT, big data and analytics, cloud computing, and AI are more used for sustainability in smart factories and agriculture.

Table A1. Cont.

Author	Goal	Results	Comments
[64] Furstenau et al.	To analyze whether scientific efforts are focused on solving existing problems to promote sustainable development.	The results show that scientific efforts are focused on driving the economic and environmental fields and highlight the lack of efforts related to social aspects.	The growing number of studies that relate Industry 4.0 and sustainability proves the strong relationship between the themes, characterizing sustainability as one of the pillars of intelligent manufacturing. To this end, this movement must be supported by big data and analytics, CPS, 3D printers, AI, VR, IoT, and robotics technologies to promote sustainability. By using 3D printer technology, it will be possible to ensure food security because it will be automatically controlled in every part of the supply chain through sensors. The benefits of applying digital technologies are definitely not in question, and big data and analytics, IoT, AI and ML systems, blockchain, and CPS are already applied. Global challenges such as climate change and global warming, drastic weather disasters, and unexpected disruptions are a growing problem in the economy. This gives one the reason to explore new and advanced possibilities of digital technologies.
[67] Hrustek	Analyze the literature in the area of sustainability and agriculture led by Industry 4.0 digital technologies.	The analysis showed the high relevance of the subject in academic and national circles. Secondly, the concepts of sustainable agriculture and sustainability-oriented agriculture in the context of digital transformation were analyzed, and it was shown that transformed agriculture can successfully deal with today's challenges. Finally, guidelines were defined for sustainable development driven by agriculture through the determinants of digital transformation.	
[68] Fekete and Rhyner	Provide a conceptual overview of the impacts of DT on social vulnerability and human risk groups that should be reconsidered to include not only existing physical humans but also their digital extensions.	The study showed that sustainable development and the interdependencies between humans and technologies have been causing an increase in products and services, especially in information technology and electricity, which is aggravated in times of crisis and is already one of the main vulnerabilities of human societies.	DT concerning risk and security research includes developments in the fields connected to the Internet, mobile devices, AI, robotics, and IoT. The application of new digital products is already being widely used in disaster risk management in certain fields.
[70] Rossato and Castellani	Conduct a study on the longevity of some companies and the factors that have kept them so long lasting and their integration with DT technologies and Industry 4.0.	The study found that the longevity of companies comes first and foremost from their continuous and family management, and in recent years, the inclusion of digital technologies and sustainability has kept companies at a competitive advantage in the marketplace.	They considered new technologies called SMACIT (Social, Mobile, Analytics, Cloud Computing, and IoT) and other technologies such as AI, blockchain, robotics, and VR to form an operational backbone with the business resources that ensure the efficiency, scalability, reliability, quality, and predictability of core operations. A digital service platform and business capabilities facilitate the fast development and implementation of innovations.

Table A1. Cont.

Author	Goal	Results	Comments
[72] Sartal et al.	Conduct an SLR to analyze sustainable manufacturing through Industry 4.0 technologies.	It was analyzed that Industry 4.0 technologies promote, regarding ecology, the reduction of waste generation through recycling and the sustainable use of energy. From the economic point of view, the interconnection of processes directly or indirectly causes an increase in performance and efficiency indicators and responsiveness.	The review noted a sustainable manufacturing approach through Industry 4.0 frameworks comprising three major components: technology, process integration, and sustainability. Technologies included IoT, systems integration, cloud computing, simulation systems, 3D printer, virtualization, and robotics, all promoting system integration that in turn leads to sustainability.
[73] Soltovski et al.	To perform a systematic literature review for an analysis of the risk points of the implementation of Industry 4.0, aiming to find the benefits and directions for a better approach to the topic.	The risks found in the research were divided into economic, social, environmental, and technological categories. Within the points addressed, issues related to cyber security were the most commented upon; on the other hand, environmental issues were in the lower ranks, such as the increase in consumption of natural resources and the increase in electronic waste.	For the authors, from a business perspective, a great technological advance can be detrimental to the companies as well as to the whole society involved. The most commonly cited digital technologies in the study were: CPS which are digital systems that manage the physical and virtual world, IoT, big data analytics, cloud computing, cyber security, AR, simulation, ML, and 3D printer (additive manufacturing).
[74] Molina et al.	Bringing the vision of digital transformation to Spanish ports that aim to promote sustainability and environmental quality.	The research result shows that the Blue Ocean strategy is considered the most ideal for Spanish ports.	Smart ports, as they have been called, cover a multitude of aspects and variables, technologies such as automation, digitalization, IoT, interoperability, transparency, decentralization, and customer experience.
[75] Elavarasan et al.	To develop a guide to direct the post-pandemic COVID-19 scenario toward the sustainable path and achievement of the 17 UN goals (SDGs).	The result shows that SDG7 is the basic goal compared to the others in a scenario where there was no pandemic and that mapping sustainable energy to the world is the first goal that must be achieved.	The need for transformation is deeply rooted and aspects of transformation are discussed in various regards, such as smart grid, blockchain, the role of AI, ML, IoT, and others.
[80] Tsai and Lai	This study, which was based on production data from a paper company, aimed to propose a mathematical programming decision model that integrates green manufacturing technologies, activity-based costing (ABC), and the theory of constraint (TOC).	The evidence from this study should improve the paper industry's competitiveness and provide insights into the value of an integrated mathematical programming model applied to decisions regarding products.	Authors noted that, with the characteristics of IoT and CPS, items such as sensors, machines, products, supply chain, and customers can be interconnected. They concluded that, in finding the most profitable product mix, companies are often limited by their short-term resources, which affects the company's profit goal, and that digital technologies significantly improve the efficiency of business operations and its sustainability.

Table A1. Cont.

Author	Goal	Results	Comments
[83] Ivascu	To propose a hierarchical framework for sustainability assessment in manufacturing industries in Romania.	The research showed that among the most important benefits are: cost reduction, competitiveness, demand for partners, financial benefits, flexibility, reliable operation, and production interruptions. The barriers refer mainly to lack of financial resources, skills, supply chain sizing, and employee resistance.	The results of this research refer to the presentation of the relationship between circular economy and Industry 4.0, which includes the trend of companies toward automation and data exchange among technologies and manufacturing processes, which include CPS, the IoT, cloud computing, cognitive computing, AI, and other implications related to these fields.
[90] Talaviya et al.	It seeks to validate the use of AI in the agricultural environment and confirm that it is an emerging technology in the field of agriculture.	There is scope for AI exploration in areas that are still a challenge for agriculture. The challenge for the full introduction of AI is still the high cost of these platforms, making them still in the early stages of their use.	AI-based machines and equipment have taken the farming system to a different level. Recent automated system technologies such as the use of agricultural robots and drones have made a huge contribution to the agro-industry sector. As an example of sustainability, the authors presented the gaseous energy sprayer.

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