

Systematic Review

# The Economic Aspect of Digital Sustainability: A Systematic Review

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**Abstract:** In recent years, sustainability and Industry 4.0 have become crucial aspects of the global economy. Numerous studies focus on the link between environmental aspects of sustainability and Industry 4.0. On the contrary, few studies address the issue of the integration of economic sustainability and digital technologies. This paper aims to fill this gap through a systematic analysis of the literature. In particular, 32 articles were selected and following a descriptive analysis to evaluate the evolution of the theme, a content analysis was performed. The findings of this study highlight and categorize the main sustainability metrics associated with digital technologies. Specifically, the digitalization process enhances the connection of products and factories, the value chain and users to achieve a production cycle as sustainable as possible. The new technologies developed allow companies to foster innovation and entrepreneurship, increase the market share, reduce energy waste, recover and reuse the material, etc. Finally, managerial and academic contributions were identified.

**Keywords:** Industry 4.0; smart manufacturing; smart production; economic sustainability; financial sustainability



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## 1. Introduction

Sustainability represents one of the most addressed issues of the last decade. This concept has evolved over the years. Initially, the term sustainability referred only to environmental features related to the reduction of carbon footprints, CO<sub>2</sub> emissions, water waste etc. Nowadays this concept has acquired a new meaning linked to the Triple Bottom Line (TBL) [1,2]. The latter was firstly introduced by Elkington in the late 90s [3]. In line with the TBL, organizations must be economically viable, environmentally friendly and socially responsible (to be considered sustainable [4]. Although sustainability has acquired a broader meaning, there is a widespread tendency to link this topic with the impact of certain systems or activities on the environment in its respective sphere of influence. Despite the apparent prevalence of the environmental factors, the social and economic aspects of sustainable development are equally important within the sustainability of companies. Nonetheless, environmental aspects of sustainability dominate the stand-alone research, on the contrary measuring its interaction with social and economic performance is less developed [5]. Companies tend to assess their impact on the economic conditions by adopting various metrics such as the Global Reporting Initiative's (GRI) sustainability indicators and Dow Jones sustainability index [6]. Parallel to the trend of organizations to comply with sustainability standards, in recent years we have seen the transition of organizations towards the model of *Smart Factories*. This phenomenon is better known as Industry 4.0. Previous contributions consider Industry 4.0 the epitome of the digitalization of manufacturing [7,8]. This transition deals with the accumulation of technology incorporated into successive generations of advanced tools and techniques [9]. According to [10], the main ideas of Industry 4.0 have also become a strategic initiative of the German government which has included this concept in the "High-Tech Strategy 2020 Action Plan". Similar strategies have also been implemented in other industrialized countries, e.g., USA ("Advanced Manufacturing

Partnership”), China (“Made in China 2025”), United Kingdom (“Smart Factory”), and others [11]. Nowadays, the fourth industrial revolution aims to achieve faster innovation in manufacturing processes with greater efficiency of the value chain [12]. Industry 4.0 allows flexibility and customization of products and services and, consequently, increases the maximization of profitability [13]. The strong emphasis on digitalisation has prompted researchers to analyze the Industry 4.0—sustainability dichotomy [14,15]. As part of the link between Industry 4.0 and sustainability, these studies evaluate the different possibilities of digital technologies in improving green practices. The implementation of Industry 4.0 in the sustainable context is favouring important changes at the organization level. In this perspective, numerous authors have expressed the need for studies on the impacts of these technologies on the economic side of the TBL [16,17]. Specifically, few studies focus on the link between economic sustainability and Industry 4.0. This paper aims to fill this gap and find the connection points between economic sustainability and Industry 4.0 technologies. This objective is addressed through a systematic review of the literature and the definition of a taxonomy of the main economic sustainability metrics related to digital technologies. In particular, we intend to answer the following questions:

- R1. How have the studies related to economic sustainability and Industry 4.0 technologies evolved?
- R2. What are the main metrics adopted in valuing the economic sustainability of digital technologies?
- R3. How does the integration of digital technologies impact the economic sustainability of organizations?

The paper is structured as follows. The next section provides a theoretical background on economic sustainability and Industry 4.0. The third section underlines the review methodology adopted. In the fourth section, the results of each methodological step are presented. The following section reports the discussion. Finally, in the last section, we defined conclusions, research limitations and implications for both academics and practitioners.

## 2. Theoretical Background

### 2.1. Industry 4.0

In the last decade, the economy has been witnessing the digital transformation of the industry. The fourth industrial revolution is now considered a successful phenomenon, rather than a pure media event [18,19]. Since the introduction of the term Industry 4.0 in 2011, the digital transformation has immediately captured the attention of industrialists and governments around the world [20,21]. Following the presentation of the German government plan, numerous initiatives were promoted by various government entities for the redefinition of modern production, aimed at a radical improvement and a deepening of the vision described, guided by the strengthened link between science, technology and industry. Liao et al. [22], in their systematic review of the literature, have reconstructed the government plans that arose in less than ten years and which therefore aim to exploit all the potential promised by the fourth industrial revolution. In 2011 the United States (USA) define a novel program called “Advanced Manufacturing Partnership (AMP)” to support manufacturing companies. In 2012, the German government approved the “High-Tech Strategy 2020” action plan, to allocate funds reserved for technological development. In 2013 the French government defined “La Nouvelle France Industrielle”, an action plan consisting of more than 30 sectoral initiatives for industrial revitalization. In 2013, the United Kingdom (UK) government presented the “Future of Manufacturing”. This plan aims to provide a policy for the growth and resilience of UK manufacturing over the coming decades. In 2014, the European Commission presented the new contractual Public-Private Partnership (PPP) on the “Factories of the Future (FoF)”. In the same year, the South Korean government announced the “Innovation in Manufacturing 3.0” program for the development of Korean manufacturing. In 2015, the Chinese government issued the “Made in China 2025” plan together with the “Internet Plus” plan, which prioritizes different

sectors in the manufacturing industry to accelerate computerization and industrialization in China. In the same year, the Japanese government adopted the 5th foundation plan for science and technology, in which special attention was paid to the manufacturing sector for the realization of its world-leading “Super Smart Society”. In 2016, the Singapore government committed nearly \$20 billion to its Research, Innovation and Enterprise (RIE) 2020 plan. Following the European elections in May 2019, the European Union set several priorities that shape the political and policy agenda until 2024. Among the various priorities, the concept of Industry 5.0 was introduced as a natural continuation of Industry 4.0 capable of providing a vision of industry that aims beyond efficiency and productivity reinforcing the role and the contribution of industry to society. Given this background, all companies in the world can only take an interest in the digital transition. In that, the adoption of Industry 4.0 technologies allows the conversion of common machines into self-aware and self-learning equipment to improve performance and overall value chain management [23,24]. Industry 4.0 ensures that manufacturing integrated with information technology, the result of this collaboration action translates into the development of “intelligent” factories that are highly efficient in the use of resources capable of adapting rapidly to the changing needs of stakeholders, to meet company objectives [25]. The advent of the fourth industrial revolution has also redefined the integration of the physical world into the organization and the cyber world through technologies such as artificial intelligence, analytics, cloud technology, internet of things, etc. [26–28]. Digital transformation has not only changed the way an organization operates but the market is also transformed by considering the entire value chain [29]. Regarding macroeconomics aspects, Industry 4.0 has developed a profound impact on factories, public and private sectors, economies, etc. Digital solutions are therefore the most important tool to overcome the crisis triggered by Covid and, at the same time, relaunch competitiveness. Digitalization is one of the main levers on which the European Commission is aiming to complete the Action Plan, while the new 2021–2027 Union programming is about to start. The central issue is that of the digitalization of industrial processes. A paradigm change that involves the digital integration of all business sectors, starting from the analysis of customer needs and the potential of the market, passing through design to get to production, and then extend to logistics and sales, and the after-sales service, in a constant flow of data that connects machinery, people and systems. It is an opportunity to integrate new production processes, new strategies, new professional figures internally, giving space to innovation, freeing up creativity and allowing you to optimize costs, speed up management, improve efficiency. There are developing countries that are already adopting Industry 4.0 solutions, such as China and India. The latter are completely changing their strategy. In the past, they were characterized by a cost of labour. This is no longer possible as Industry 4.0 requires highly specialized operators.

Although Industry 4.0 is one of the most discussed topics among practitioners and academics in recent years, no single and commonly accepted definition of this concept has been developed [30,31]. Researchers and industrialists have divided opinions on which elements constitute Industry 4.0, how these elements are related and where Industry 4.0 technologies apply. Previous contributions show over 100 different definitions of Industry 4.0 [32]. According to the authors, the definition that well reflects the idea of Industry 4.0 is the one proposed by [33]: “Industry 4.0 describes the transition from centralized production to very flexible and self-controlled production. Within this production, products, all affected systems and all stages of the engineering process, are digitized and interconnected to share and transmit information and to distribute this information along vertical and horizontal value chains and beyond in broad networks”. From this definition, it is clear that Industry 4.0 must be integrated with paradigms already adopted in organizations such as the sustainable one.

## 2.2. Economic Sustainability

Sustainability is a broad concept that addresses most aspects of organizations [34]. This is not limited to the environment but also concerns economic and social resources [1,2].

Specifically, economic sustainability is about long-term economic growth while preserving environmental and social resources. Economic sustainability is not so far from the balance between natural resources, social well-being and ecosystems [1]. Generally, sustainability is considered a movement to ensure better and more sustainable well-being for all. Although sustainability is a relatively new concept, it has its roots in movements such as conservationism or socio-economic justice [35]. The concept of economic sustainability has gained even more importance in the supply chain in the last two decades [36]. Indeed, the constant increase in global competition has prompted companies to adopt sustainable practices to improve their economic performance [37]. In the TBL approach, economic sustainability acquires a new meaning, it is not only the traditional corporate capital. In this sense, corporate capital should be measured in terms of the impact of the business activity on the economic environment in which it operates. The business that strengthens its economy will continue to be successful in the future, as it contributes to the overall economic health of its networks and community. Of course, a company shouldn't neglect its traditional profits. According to [38] economic performance can be made operational in terms of market, operational or accounting metrics. In recent years, the economic sphere of sustainability has been neglected in favour of the social and environmental aspects. Nonetheless, in December 2019 the EU introduced the Green Deal which defines the strategies to be followed to move to a sustainable economy. Among the tools identified that help the EU achieve its ambitions, there is the digitalization of industry through the use of enabling technologies such as big data and artificial intelligence. When the full integration of digital technologies into corporate business models is achieved, companies will be able to fully perceive not only environmental but also economic benefits through a better corporate image, energy savings, reduction of material costs, and resource efficiency. There is therefore a very strong link between economic sustainability and digitalization that needs to be expanded and detailed to identify the main metrics for measuring the effectiveness of this business digitalization process. Given the above, this study aims to investigate the role of economic sustainability in the context of increasing digitalization.

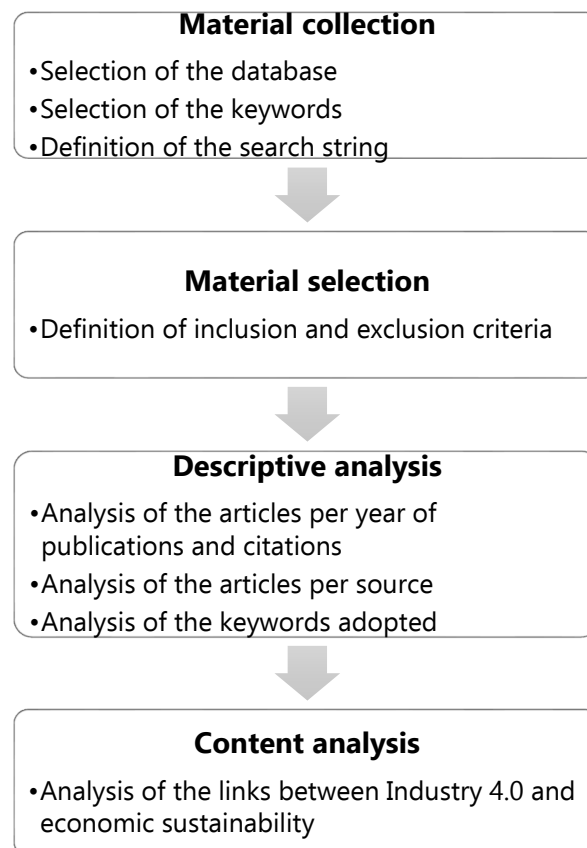
### 3. Methodology

This study was carried out based on a systematic approach in line with different previous contributions [39,40]. A comprehensive systematic literature review methodology is performed to analyse and describe the links between Industry 4.0 technologies and the economic sphere of sustainability. This approach is particularly useful when researchers aim to provide a transparent and reproducible approach [41]. In particular, this method allows us to fully identify, evaluate and summarize all relevant articles on the topic under analysis [42].

Figure 1 depicts the four different stages of the methodology adopted.

1. **Material collection.** This section includes the data collection and the selection phases, and involves the following sub-phases:
  - a. Selection of the database. This phase includes a detailed discussion about the academic database(s) to use.
  - b. Selection of the keywords. This phase is based on a brainstorming process that involves two researchers plus a third expert in case of uncertainty to find the most suitable keywords to be used to collect papers.
  - c. Definition of the search string. This phase deals with the identification of the search string through the use of Boolean operators to include all the relevant articles in the sample. Besides, this phase reports any filters used to limit the time range analysed and the source types selected to collect data (e.g., journals, book chapters, conference proceedings).
2. **Material selection.** This phase discusses the inclusion and exclusion criteria identified to select only papers that are aligned to the topic under investigation.
3. **Descriptive analysis.** This section consists of a brief overview of the selected articles according to the following descriptive perspectives.

- a. Analysis of the articles per year of publication and number of citations. In this phase, the evolution of the number of reviews published over time and citations received, are analysed
  - b. Analysis of the articles per source. This phase includes a discussion about the source of the articles.
  - c. Analysis of the keywords adopted. In this phase, the keywords adopted by previous authors are identified and analysed.
4. **Content analysis.** This section reports and groups the main metrics related to economic sustainability according to different Industry 4.0 technologies.



**Figure 1.** Review methodology.

#### 4. Research Results

This section includes the results obtained from the implementation of each step of the review methodology.

##### 4.1. Material Collection

This phase starts with the choice of database. Specifically, the literature search employed the Scopus database since it provides integrated results from a variety of databases, including Science Direct, Emerald Insight, Springer Link, Wiley Online Library, etc. The query on the databases was performed in March 2021. This review includes only English-speaking formal literature (excluding books, research reports and so on). No filter was used to limit the time range and country. Furthermore, an expert in sustainability and digital technologies was involved in the choice of keywords. Table 1 reports in detail the search string adopted and the total number of articles that resulted.

**Table 1.** Search string adopted.

Search String	Number of Articles
((“Industry 4.0” OR “digital technologies” OR “smart factories” OR “smart manufacturing” OR “smart production”) AND (“financial” OR “economic” AND “sustainability”))	252

#### 4.2. Material Selection

As Table 1 outlines, 252 articles resulted from the query. Following [43,44], to consider only the articles relevant to the topic under investigation, we have defined two selection criteria. The first is based on the reading of the title and abstract, the second on the reading of the full text. The title and abstract of each article have been screened to check the adherence of the paper to the general topic. For example, papers that focus only on Industry 4.0 and are not related to its impact on economic sustainability were excluded. The output of the screening is a list of 43 articles. Subsequently, we read the full text of the papers selected. This step allowed the exclusion of the others 12 papers. Table 2 presents the results of the material selection phase.

**Table 2.** Selection criteria.

Selection Criteria	Number of Articles Excluded
Initial Sample	252
Title and abstract screening	−209
Full-text screening	−11
Final sample	32

#### 4.3. Descriptive Analysis

The descriptive analysis aims to provide a brief overview of the selected articles that focus on the integration of and economic sustainability and Industry 4.0. Three descriptive perspectives of analysis were identified:

1. Papers and citations over time.
2. Papers by source.
3. Papers by methodology.

##### 4.3.1. Papers and Citations Over Time

Figure 2 presents the evolution of papers and citations over time. The selected body of literature comprises papers that have been published in 11 years ranging from 2010 to 2021 (March). As Figure 2 shows, most of the papers have been published in the more recent years, starting from 2017, with the highest number of works (8) published in 2020, thus highlighting the increasing interest devoted to Industry 4.0 and economic sustainability by academics. Indeed, this growing trend stops in 2021 only since the selection of the material considered the first three months of the year. Concerning citations, there are two peaks in 2013 and 2019. More in detail, the most cited article in the sample is dated 2013 with 520 citations [45].

##### 4.3.2. Papers by Source

Figure 3 depicts the distribution of papers by source. Specifically, the Journal of Cleaner Production dominates in terms of the number of relevant studies, with 6 articles, followed by Sustainability (Switzerland) (4 papers), International Journal of Production Research and Procedia CIRP (2 papers each).

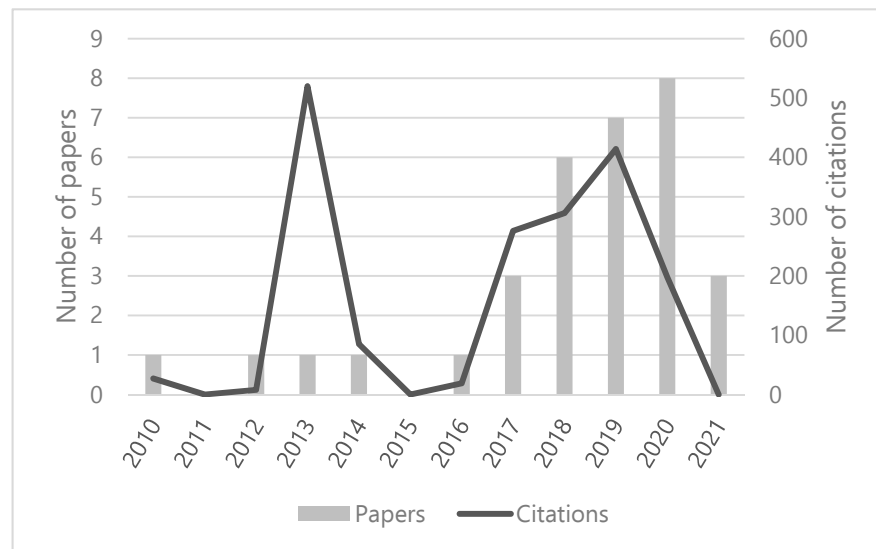


Figure 2. Papers and citations by year of publication.

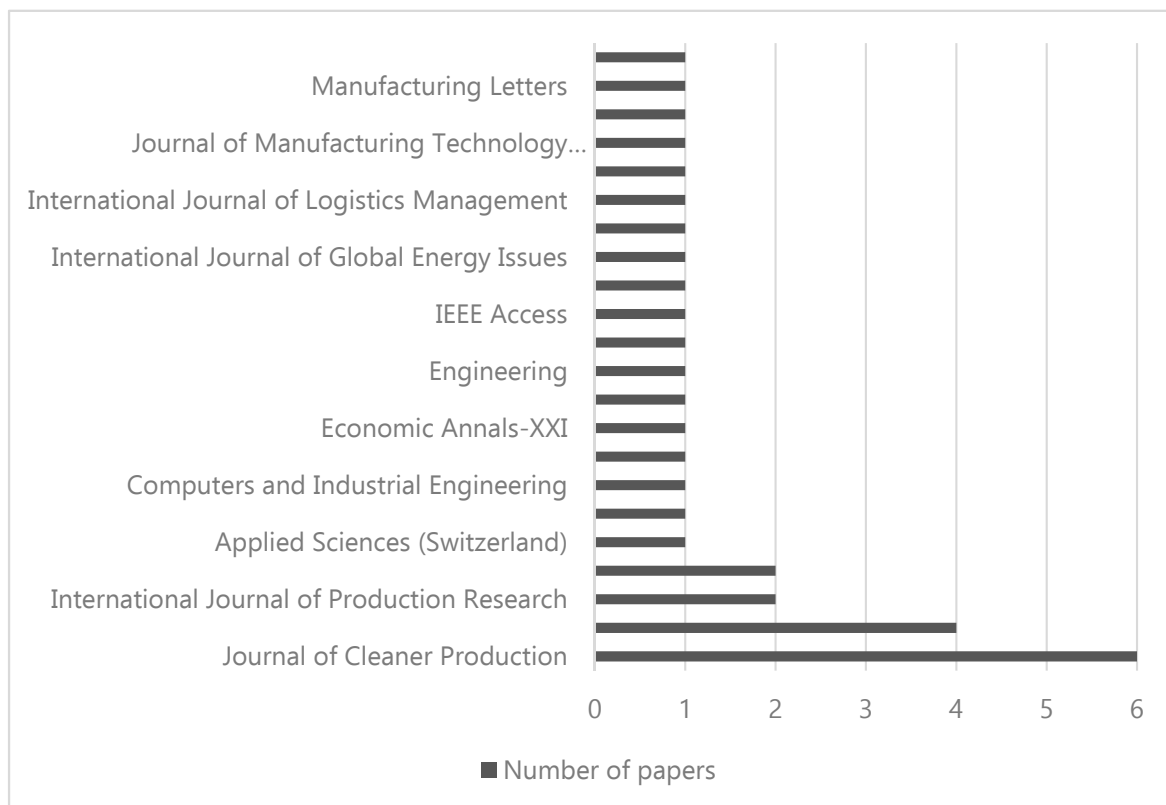


Figure 3. Papers by source.

#### 4.3.3. Papers by Keywords

Figure 4 presents the frequency of the keywords in the sample of articles. Half of the papers adopt the keyword Industry 4.0, followed by sustainability. The other most frequent words are related to specific technologies (big data, cyber, additive manufacturing, internet of thing, cyber-physical systems). TBL has a frequency of 13%. Finally, all other keywords contribute less than 10% to the total sample.

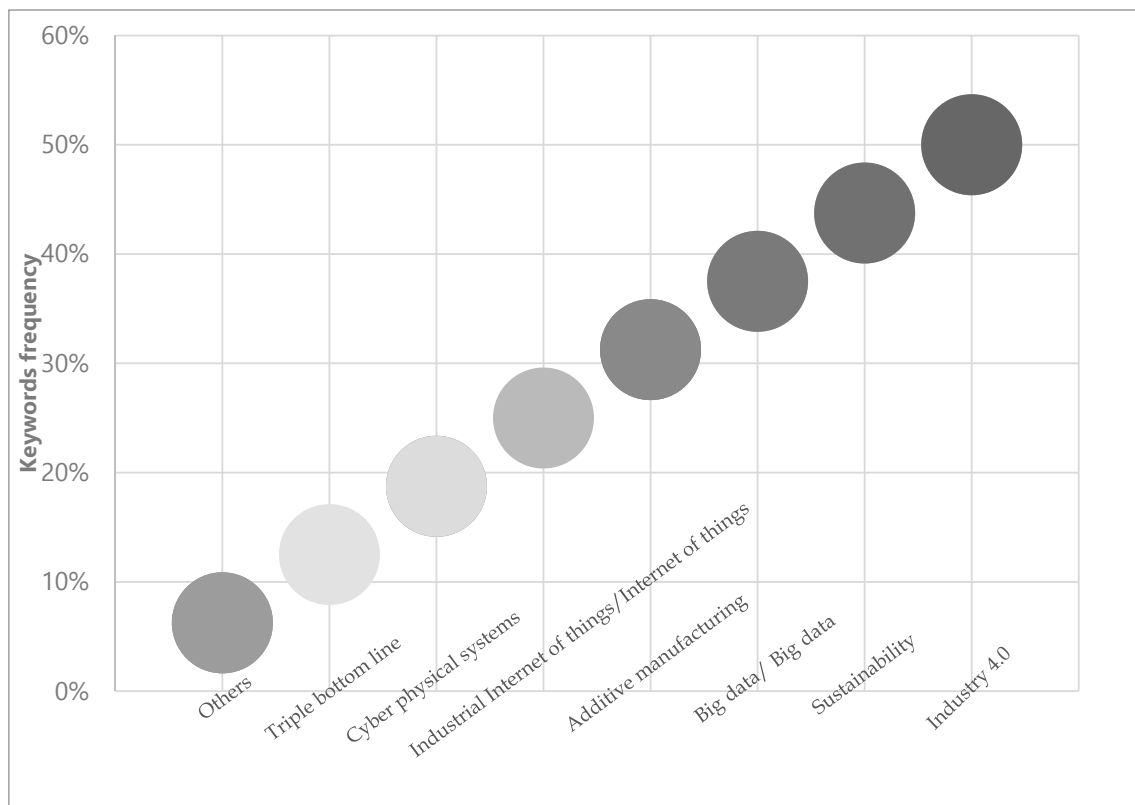


Figure 4. Keyword's map.

#### 4.4. Content Analysis

The analysis of the content of the 32 articles aims to provide a more detailed overview of the papers included in the body of literature on economic sustainability in the Industry 4.0 context. Afterwards, the papers have been analysed regarding the metrics adopted in valuing the financial sustainability of Industry 4.0 technologies. We identify 21 unique different metrics. These last were distinguished in two different areas as shown in Table 3. Specifically, direct metrics have an impact on the economy of the company, on the other hand, indirect metrics impact the global economy of the environment in which operate.

Table 3. Classification of economic sustainability metrics.

Economic Sustainability Metrics	Direct	Indirect
1. Competitiveness	x	
2. Customization		x
3. Economic development		x
4. Efficiency	x	
5. Extension of product/equipment life cycle		x
6. Fostering innovation and entrepreneurship		x
7. Market share	x	
8. Reduction of material consumption		x
9. Process quality	x	
10. Production costs reduction	x	
11. Productivity	x	
12. Profitability of investments	x	



**Table 3.** *Cont.*

Economic Sustainability Metrics	Direct	Indirect
13. Reduction of delivery times	x	
14. Reduction of energy consumption		x
15. Reduction of inventory inaccuracy	x	
16. Reduction of production mistakes and accidental damages	x	
17. Reduction of transportation costs		x
18. Reduction of waste costs		x
19. Reduction of water consumption		x
20. Resources recovery		x
21. Sales growth	x	

Following the classification, the metrics were associated with Industry 4.0 technologies. More in detail, the in-depth analysis of the articles revealed 9 technologies, each associated with both direct and indirect metrics (Table 4).

**Table 4.** Economic sustainability metrics according to Industry 4.0 technologies.

Industry 4.0 Technologies	Economic Sustainability Metrics	References
Additive manufacturing	Customization Economic development Efficiency Extension of the product/equipment life cycle Market share Process quality Productivity Profitability of investments Reduction of delivery times Reduction of water consumption Reduction of inventory inaccuracy Reduction of production costs Reduction of transportation costs Reduction of waste costs Reduction of transportation cost	[46–51]
Artificial intelligence	Competitiveness Customization Economic development Extension of the product/equipment life cycle Fostering innovation and entrepreneurship Market share Reduction of water consumption Reduction of production mistakes and accidental damages Reduction of waste costs Resources recovery	[52–54]
Big data	Competitiveness Customization Economic development Efficiency Extension of product/equipment life cycle Fostering innovation and entrepreneurship Market share Process quality Productivity Reduction of water consumption Reduction of material consumption Reduction of production costs Reduction of production mistakes and accidental damages Reduction of waste costs Resources recovery	[52,54–62]

Table 4. Cont.

Industry 4.0 Technologies	Economic Sustainability Metrics	References
Blockchain	Economic development Efficiency	[63,64]
Cloud	Efficiency Process Quality Productivity Reduction of water consumption Reduction of material consumption Reduction of water consumption	[61,65]
Cyber-physical systems	Process quality Productivity Reduction of production costs Reduction of water consumption	[59,66,67]
Internet of things	Competitiveness Customization Economic development Efficiency Extension of product/equipment life cycle Fostering innovation and entrepreneurship Process quality Productivity Profitability of investments Reduction of water consumption Reduction of material consumption Reduction of production costs Reduction of production mistakes and accidental damages Reduction of waste costs Resources recovery Sales growth	[52,54,61,68–72]
Radio frequency identification	Efficiency Reduction of inventory inaccuracy	[73,74]
Robotics	Competitiveness Process quality Reduction of production costs Reduction of water consumption Reduction of production mistakes and accidental damages Reduction of waste costs	[52,67]

## 5. Discussion

The analysis of the content allows us to identify a list of metrics that measure the potential benefits of Industry 4.0 technologies in term of economic sustainability. The union between economic sustainability and industry 4.0 represents a billion-dollar economic opportunity that, through strategies in terms of interconnection and cooperation capacity of productive resources. From the analysis of the literature emerged that it will cause an increase in competitiveness and efficiency and will favour the development of new business models to the point of completely revolutionizing the entire industrial sector. The transition to a sustainable industry model must be guided by a company digitalization process that enhances the connection of products and factories, the value chain and users to achieve a production cycle as sustainable as possible. The new technologies developed allow the company to save capital, reduce energy waste, recover and reuse the material, mixing traditional knowledge and new skills, recover more traditional areas to promote new development. From the point of view of the direct effect, the use of technologies such as the internet of things and artificial intelligence increases the efficiency and flexibility of production by facilitating communication with stakeholders (e.g., customers, suppliers, distributors) [75]. In addition, Industry 4.0 allows the transition to mass customization, optimizing customer requests, reducing waiting times and increasing customer satisfaction [76]. In the long run, these technologies also positively impact company profitability through the optimization of material flow, reduction of time to market, space optimization, efficient use of resources, reduction of waste, lower inventory costs [77,78]. Furthermore,

Industry 4.0 favours the creation of new open business models. From the indirect impact point of view, digitalization offers several opportunities to reduce the waste of natural resources and the consumption of materials [2]. Besides, while it eliminates many low-skilled jobs, it also creates new job opportunities [79]. Ghobakhloo et al. [20] have highlighted that in many cases the technology acts as a catalyst, for least developed countries, to accelerate the process of economic modernization. Industry 4.0 is changing the way companies produce, consume, trade and live. This phenomenon has affected all the economic sectors from medical to energy [80]. The use of technologies facilitates the development of products that respect the global economy [81]. The digital transformation is changing the way human resources work [82]. The simplification and automation of processes, with consequent improvement of the decision-making process, improve the efficiency of human resources [83]. The use of smart tools allows employees and managers to communicate in a more free and interactive way, reducing the communication gap between leadership, middle management and employees [84]. The use of artificial intelligence and data analysis can offer personalized professional development schemes or learning programs based on the experience and personality of each employee. Automation, interoperability, contribute to production efficiency, also improving control measures [85,86]. Robots, automated vehicles, intelligent machines are replacing humans in numerous activities such as inventory monitoring, quality control and product distribution [87]. Experts expect Industry 4.0 to eliminate most of the jobs with medium-low qualifications that will be compensated by creating new job opportunities in the IT, mechatronics and engineering areas [14]. Greater productivity, better process stability, product customization and reduction of waste and delivery times are among the other sustainability opportunities offered by the modular approach of intelligent manufacturing [88]. In conclusion, this study extensively analyzes the economic implications of the use of Industry 4.0 technologies. Through the classification shown in Table 4, it is noted that some technologies have been studied in detail and numerous metrics have been identified for the assessment of economic sustainability. Other technologies such as radio frequency identification, blockchain and cyber-physical systems are instead little analyzed and in this sense, few economic sustainability metrics have been identified. In addition, has emerged a scarcity of studies that evaluate the use of technologies in a combined way.

## 6. Conclusions

In recent years, sustainability and Industry 4.0 have become crucial aspects of the global economy. In the literature, numerous studies focus on the environmental aspects of sustainability with a focus on digital technologies. On the contrary, few studies address the issue of digital economic sustainability. Based on the analyzed literature, three research questions were defined (R1; R2; R3).

The systematic literature review methodology was used to answer the research questions identified. Following the execution of a review protocol, 32 articles were selected on the link between Industry 4.0 and financial sustainability.

Considering question R1, it is possible to conclude that the use of I4.0 technologies is opening up new scenarios in the field of economic sustainability. There is a positive trend in the number of articles published, heterogeneity of sources and keywords used by the authors.

Considering question R2, the analysis of the content of the articles allow us to identify and categorize 21 metrics. The latter were grouped according to the effect on the economy (direct/indirect) and the digital technologies.

Finally, about the impact of digital technologies on the sustainability of organizations, emerged that these tools are not only changing the concept of sustainability itself, but also the way of designing, assembling, selling and maintaining products and processes. The use of digital technologies facilitates the implementation of organizational activities, improving productivity, reducing consumption and consequently costs, making modular workstations and flexible production lines. On the other hand, it favours the development

of economic sustainability in an indirect perspective of reducing waste, energy and water consumption. From the point of view of academics, this study represents a starting point for future empirical studies that could exploit the metrics identified. Regarding the managerial contribution, the taxonomy presented can represent a useful tool for the delineation of the characteristics of the technologies, to guide practitioners in the choice of future investments. Some gaps emerge from the literature. There has been growing interest in the application of blockchain technologies, cyber-physical systems and radio frequency identification but there is a lack of research into the impact of those technologies at the operational level. It is necessary to investigate more carefully the type of digital technology to be implemented concerning the sector or the type of activity carried out by the organization to improve economic sustainability. Another relevant topic is the analysis of the impact of the combined use of different industry 4.0 technologies. Specifically, future studies could identify strategies to increase economic sustainability performance through the combined use of enabling technologies and conduct real application cases.

Although this study has tried to highlight the possible metrics deriving from the use of digital technologies, it has a limitation related to the review protocol adopted that may have excluded some relevant contributions.

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