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Review

Industry 4.0: a step towards achieving the SDGs? A critical literature review

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Abstract
The transformation of industrial production is one of the big challenges on the pathway to sustainable development. Therefore, expectations regarding the contribution of Industry 4.0 are high. So far there is only little research focusing on the relation between the Sustainable Development Goals (SDGs) of the United Nations 2030 Agenda and the digitalization of industrial processes. We argue that sustainability aspects must be an integral part of Industry 4.0 implementation to support a sustainable development. For that reason, the digital manufacturing concept itself must take essential characteristics of sustainability into account. Our analysis has investigated to what extent sustainability aspects are currently reflected in the most recognized articles about Industry 4.0. For that purpose, we have conducted a systematic literature review, in which we have analysed the top cohort of most frequently cited articles published after 2013 on GoogleScholar dealing with "Industry 4.0". Our literature review reveals that the descriptions reflect many expectations and hopes while only few of them are evidence-based. According to our results Industry 4.0 mainly deals with the economic dimension of sustainability such as growth and productivity. Although there are expectations that Industry 4.0 creates a window of opportunity for a more sustainable production, we could not find evidence to support this idea. Instead of targeting a more sustainable production, many descriptions draw a picture in which Industry 4.0 processes run exactly as before, just in a digital way.

Keywords SDGs · Industry 4.0 · Sustainability · Digital Manufacturing · Literature review

1 Introduction

The transformation of industrial production is one of the big challenges on the pathway to sustainable development. The United Nations Environment Programme speaks of a *"new economic paradigm—one in which material wealth is not delivered perforce at the expense of growing environmental risks, ecological scarcities and social disparities"* [1]. Industry 4.0 is characterized as a fundamental transformation or in other words a *"fourth industrial revolution enabled by Internet technologies to create smart products, a smart production, and smart services"* [2].

There is no single coherent definition of the term Industry 4.0 in scientific literature. However, some of the most recognized publications describe Industry 4.0 as a modern manufacturing concept based on digital and virtual processes in which manufacturing systems and to-be-manufactured products are interconnected through the means of information and communication technology (ICT) and cyber-physical systems. Manufacturing processes are executed by decentralized, intelligent and partially autonomous machinery, with the ability to self-organize. Industry 4.0 factories are highly flexible, enabling the application of self-optimized manufacturing processes that facilitate mass customization [3–6].

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Despite these technological advancements, Industry 4.0 offers several challenges for all three dimensions of sustainability [7]. Regarding the social dimension, growing inequalities [8] and increasing disparities in industrial employment [9–11] need to be mentioned, while the debate on the environmental implications is focusing around issues like enabling circular economy or supporting other resource-conserving methods [12, 13] and the energy consumption of digital services and applications, which continues to rise [14]. Among the economic challenges collapsing industrial sectors, and the enormous concentration of power regarding ICT manufacturing and digital services such as cloud computing [15, 16] are discussed most prominently.

However, expectations concerning the contribution of Industry 4.0 to sustainable development and the achievement of the Sustainable Development Goals (SDGs) of the United Nations 2030 Agenda are rather high [17, 18] especially among policy makers and representatives of the industrial sector [19–21]. The Global e-Sustainability Initiative (GeSI), an initiative of ICT companies, proclaims ICT has the *"potential to generate powerful environmental, economic and social benefits"*, ranging from reducing CO_2 emissions (20%), to generating additional revenues (over $11 trillion) to wider societal benefits (through connecting another 2.5 billion people) by 2030 [22]. Even though all these expectations can hardly be fulfilled, it seems likely that the goals of sustainability must be an integral part of the Industry 4.0 concept to include sustainability criteria from the very beginning of technological change. Currently hardly any dedicated research focusing on the overlap between Industry 4.0 and the SDGs is taking place. This research would be important to help shape the research agenda and thus also the implementation of Industry 4.0.

However, the views or mindsets towards a concept, as well as its understanding, do determine the way in which the activities for the subsequent implementation of the concept itself are carried out [23–25]. Conversely, this means that Industry 4.0 can only lead to a more sustainable development if the concept already takes into account essential characteristics of sustainability. For this reason, in our analysis we investigate to what extent sustainability aspects have been reflected in the most recognized articles from science and practice on Industry 4.0. Thus, we analyzed text fragments from those (not exclusively scientific) publications that describe the concept Industry 4.0 or the anticipated consequences of its implementation with the targets and indicators of the UN Sustainable Development Goals (SDGs). We chose the SDGs as a reference point because they deliver a set of goals, targets and indicators regarding sustainable industrial development and are the result of an international participatory process involving national representatives and experts. Accordingly, we want to research the question: In how far does the established interpretation of the concept Industry 4.0 and its anticipated impacts relate to the UN Sustainable Development Goals?

Unlike the Millennium Development Goals, often interpreted as a precursor to the SDGs, all targets and indicators of the SDGs are comprehensively aiming at both developed and developing economies. We focus our analysis on the SDGs 8, 9 and 12 (see Appendix 2 for an overview of SDGs 8, 9 and 12 and their respective targets), as these appear to be the most relevant ones with respect to industrial production.

In the following section we present the methodology we have chosen to address the presented research question through a systematic literature review. The results of this review are presented in Sect. 3 sorted per SDG, while the main take-aways of the results are discussed in the subsequent Sect. 4. The paper concludes with Sect. 5, which offers some general conclusions drawn from the presented analysis and an outlook for future research.

2 Material and methods

This literature review focusses on the established understanding and anticipated consequences of the Industry 4.0 concept and seeks to analyze how they align with SDGs 8 (decent work and economic growth), 9 (industry, innovation and infrastructure) and 12 (responsivle consumption and production) and their respective targets and indicators. In order to enable a focused and stringent investigation, we have limited our analysis to these SDGs, which correlate directly with the industrial character of Industry 4.0. Other SDGs such as SDGs 1 (no poverty), 7 (affordable and clean energy), 13 (climate action), which could possibly be indirectly associated with industrial production too, were therefore deliberately neglected. We operationalize the established understanding through the characterization of the concept found within the top cohort of literature on Industry 4.0 prevailing by the time the analysis was started. For this analysis, the top cohort is defined as a set of ranked publications with the following inclusion criterion: the successor offers more than 50% of the citations of its predecessor (see Appendix 1 for the ranked list of included publications).

We have used *Industry 4.0* as the search string for the according query which was conducted in early 2019. Only items published after 2013 were included in the survey, since the implementation recommendations for the future project Industry 4.0 were officially presented in April 2013 by the *Industrie 4.0 working group*. In order to depict the prevailing understanding of Industry 4.0 as it has been established—not only in academia but also in practice—*Google Scholar* was selected instead of an exclusively scientific database. The search provided us with our research object: a list of publications which is ranked after the number of their respective citations. A visual representation of the search process is provided in Fig. 1.

All monographies and publications not complying with basic scientific rules, such as proper referencing, have been excluded from the analysis. After this selection process our body of literature consisted of 40 journal articles, six conference papers, three white papers and two research reports. Table 1 provides an overview of some charatestics of our body of literature. It displays the affiliations of authors, the location of these organizations and the outlets that have published the work. For this overview we have counted affiliations and countries only once per publication even if more than one author from that origin contributed to the publication. Affiliations, locations and outlets that occurred only once are not displayed in Table 1. Authors from different countries have collaborated on eight different publications.

In every publication we have manually identified relevant text fragments, which describe characteristics for or potential consequences of the concept Industry 4.0 and managed them and the according additional meta information in MS Excel. Overall, 684 text fragments could be identified. If the Industry 4.0 concept is to make a contribution to the SDGs, it is imperative that their characteristics are part of the understanding of the concept. Hence, for all identified text fragments, we have analyzed whether their content relates to the targets or indicators defined in the SDGs 8, 9 and 12 and documented corresponding matches (see an overview of all targets for these three SDGs in Appendix 2).

3 Results

This section presents the content of the text fragments that address the targets or indicators mentioned in SDGs 8, 9 and 12 sorted by the respective SDG. SDG 8 is the one referred to most frequently among these three SDGs (see Fig. 2).

3.1 SDG 8: promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

A total of 120 text fragments are referring to topics pertaining to SDG 8, targets 8.3 and 8.5 being the most frequently addressed ones (see Fig. 3). The targets of SDG 8 relate to economic (8.1, 8.2), social (8.5, 8.6, 8.7, 8.8), socio-economic (8.3) and a combination of economic & ecological (8.4) topics.

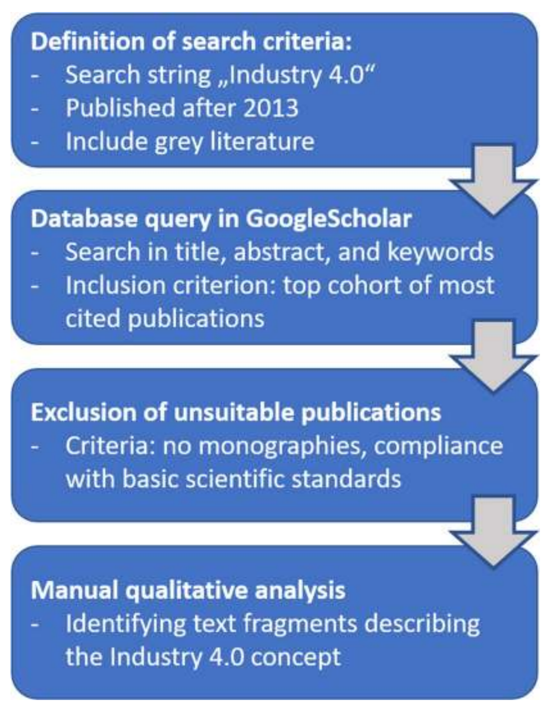

Fig. 1 Logical sequence of the search process to identify the body of literature

Table 1 Overview of the body of literature: affiliations of authors, their location and publishing outlets

Affiliations	Location	Outlets
4 publications:	***25 publications:***	***10 publications:***
German Research Center for Artificial Intelligence, Germany	Germany	Procedia CIRP
University of Stuttgart, Germany	***7 publications:***	***3 publications:***
3 publications:	United States of America	International Journal of Production Research
University of Cincinnati, United States of America	***6 publications:***	IFAC-PapersOnLine
2 publications:	China	***2 publications:***
Aachen University RWTH, Germany	***4 publications:***	Computers in Industry
Fraunhofer Austria Research GmbH, Vienna, Austria	Austria	Journal of Industrial Engineering and Management
Luleå University of Technology, Sweden	United Kingdom	
Old Dominion University, United States of America	***3 publications:***	
Ostwestfalen-Lippe University of Applied Sciences, Germany	Sweden	
South China University of Technology, China	***2 publications:***	
Technische Universität Berlin, Germany	New Zealand	
University of Bath, United Kingdom	Taiwan	
Vienna University of Technology, Austria		

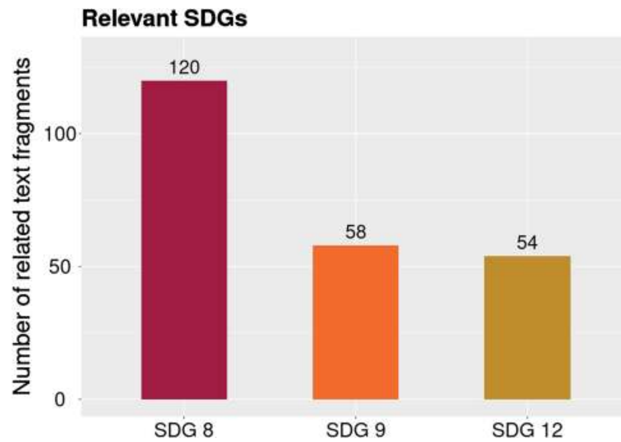

Fig. 2 Number of analyzed text fragments relating to SDGs 8, 9 and 12 respectively

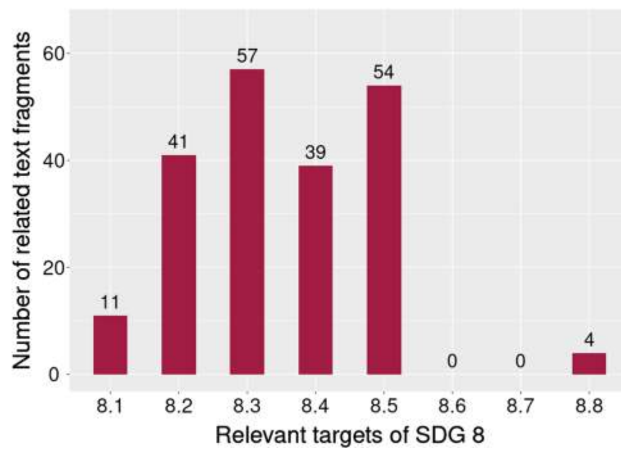

Fig. 3 Number of analyzed text fragments relating to the relevant targets of SDG 8 respectively

Target 8.1 and 8.2 both relate to economic parameters like growth and productivity, which is why they are measured by the indicators like annual growth rate of real GDP per capita and per employed person [26]. 11 text fragments draw on the topics mentioned in target 8.1, focusing on economic growth in particular in least-developed economies. The majority of these text fragments refer on a more general level to economic benefits [27] and potentials [28], improved competitiveness [29–31] or accelerated growth [30, 32]. As an example, one paper argues Industry 4.0 *"[…] will increase manufacturing productivity, shift economics, foster industrial growth […] ultimately changing the competitiveness of companies and regions"* [30]. Only one paper explicitly addresses economic opportunities for less developed countries, claiming that the virtualization of the supply chain, as one concept of Industry 4.0, will open up development opportunities for emerging economies [33]. None of the papers contextualizes these statements with specific national circumstances.

The topics centered on the productivity of economies mentioned in target 8.2 are addressed by 41 text fragments. Most of these fragments refer to a general increase in productivity [29–31, 34–37] or an improved productivity through efficiency gains [29, 31, 35, 38–41] under Industry 4.0 conditions. However, it remains unclear on which research results or calculations these statements suggesting efficiency and productivity gains are based on. One text fragment that can be considered as exemplary reads *"Industry 4.0 will allow us to achieve unprecedented levels of operational efficiencies and accelerated growth in productivity"* [32]. In many text fragments efficiency gains are mentioned as a *"byproduct"* of the innovative Industry 4.0 environment such as cost-efficient batch size one production [3, 33, 42], cloud manufacturing [42, 43] or the cross-linking of data [41, 44], which implicitly rather relate to the company level than entire economies. Generally, only few publications are taking a macroeconomic perspective indicating productivity gains through disruptive innovations. One of these exceptions is referring to the entire manufacturing industry, forecasting disruptive innovations such as *"distributed organization of production, with connected goods (products with communication ability), low-energy processes, collaborative robots, and integrated manufacturing and logistics"* [2]. A similar disruption in this sector, with the potential to affect the overall productivity of economies, is described in [29] foreseeing a *"fundamental paradigm shift towards decentralized and individualized production, which will enable new, internet-based services and business models ",* where traditional *"supply chains will evolve into highly adaptive supply networks "*. A 30% increasement of productivity for the electrical industry through the Industry 4.0 concept is stated in [36]. In a another publication the Made-in-China 2025 policy, where Chinas intention to transform its industry from labor intensive to knowledge intensive has been explicitly stressed, a analyzed [33]. Other forecasts regarding shifts in labor-intensity are more prominently tackled with the targets 8.3 and 8.5.

The future of employment and changing working conditions have become central to the ongoing public and scientific debate about Industry 4.0. It is not clear to what extent Industry 4.0 is expected to support the creation of decent jobs as demanded by SDG 8. Target 8.3 and 8.5 both set the focus on employment and decent working conditions. 57 text fragments relate to the topics mentioned in target 8.3, more than to any other target. The majority of these statements refer to the future quality of industrial work, mostly on a more general level [29, 37, 39, 43, 45–49]. In that manner they are forecasting *"a minimum intervention of human[s]"* [47] or an *"[i]mproved […] human interaction"* [48] in the future manufacturing processes or more visionary *"transforming the traditional work-as-survival to work-for-life, to a final life-as-work"* [37]. Some of the text fragments can be linked to the future *"decency"* of jobs under Industry 4.0, suggesting how human workers will be supported in coping with digital working environments [29, 33, 44, 50–52] and how new technologies will make this environment safer [33, 34, 36, 50]. Authors suggest, for example, working in Industry 4.0 *"will free up more time for people to pursue their interests, which in turn enables more diverse and flexible career paths and will allow people to keep working and remain productive longer"* [37]. Additionally, new technological tools will be applied with the potential to improve working conditions through *"chronological and spatial flexibility"* [39] and *"increasing the intrinsic motivation and fostering creativity by establishing new CPS-based approaches of work organization and design"* [41].

While according to our analysis it remains unclear in how far Industry 4.0 will lead to the creation of decent jobs as demanded by target 8.3, some publications forecast staff demand will raise for highly qualified personnel at the expense of their lower qualified colleagues [29, 31, 39, 41]. Additionally, it is expected that *"new professions for employees will emerge"* [29]. Only one publication [31] raises awareness for potential social distortions as a consequence of applying the Industry 4.0 concept on a broader scale.

Regarding the *"growth of micro-, small- and medium-sized enterprises"* demanded by target 8.3, one publication anticipates an improvement in information flow which will increase chances for small and medium-sized enterprises to become part of supply chains [43]. Moreover, opportunities for small and medium-sized enterprises due to greater flexibility of supply networks and the increasing demand for customized products expected are seen in the future [29]. All other issues included in target 8.3 like entrepreneurship or financial services have not been addressed in the analyzed body of literature.

Target 8.5 is strongly centered around the topics employment and work, which have already been presented in the paragraphs above in the context of the vaguely phrased *"decent job creation"* in target 8.3. The more specific issues in targets 8.5, namely employment for young people and persons with disabilities as well as equal pay, have not been addressed in the analyzed body of literature. Due to its comprehensive character, target 8.3 is also related to the work safety and security issues raised in target 8.8. Therefore, safety aspects of working environments have been discussed in the respective paragraphs on target 8.3. None of the analyzed publications was referring specifically to the further aspects of target 8.8 namely labor rights, migrant workers or precarious employment. Unlike improving employment chances for older people, which is stated in [29], effects on employment for young people, being essential to target 8.6, was not addressed by any of the publications. The same applies for issues like child labor and forced labor that are central to target 8.7.

Ecological aspects are at the core of target 8.4, specifically demanding to improve global resource efficiency and to decouple economic growth from environmental degradation. 39 text fragments address this target, of which 18 refer to resource efficiency [3, 29, 36, 37, 41–43, 47, 53–55] and 16 more specifically to energy efficiency [2, 27, 29, 37, 41, 42, 47–49, 55] as the two most prominent topics. Most of these statements do not provide any explanation or reasoning for these suggested improvements: Industry 4.0 is expected *"to present solutions to issues that need to be dealt with (such as the resource and energy efficiency, urban production, demographic change)"* [43]. The technological development in the context of Industry 4.0 is believed to contribute to *"a concept towards a holistic resource efficiency"* [41], *"improve resource productivity and efficiency"* [37] and give rise *"to completely new innovations with added value and business models that support optimal resource utilization and smart control"* [53] and thus *"[…]make a substantial contribution to the sustainable development of the company"* [29]. Where reasons are given, they remain on a rather general level, e.g. arguing that the improvement in efficiency is based on *"the detailed information on each point of the production process […]"* which makes it possible to optimize resource and energy *"[…] over the entire value network (this means optimal resource and energy productivity, optimal resource and energy efficiency)"* [29]. Another approach to improve efficiency is *"to consider resource* *and energy efficiency already in the planning stage of the company by the optimization of rooms, spaces, pathways or lines, by the design of centralized and decentralized supply and disposal systems or by creating closed material and energy cycles"* [29]. Two more specific reasons for an improved resource efficiency are predictive maintenance [47] which is thought to avoid machine breakdown while also reducing waste through defect products, and a more transparent energy management [27, 29, 36, 47].

Even though no publication explicitly addresses the topic of an actual decoupling of economic growth from resource consumption, some do address issues leading into that direction, like opportunities for a sharing or circular economy. One paper claims potential for *"on-demand use and efficient sharing of resources"* through digital technologies [43]. On a similar notion, Stock and Seliger [41] point towards the opportunity for digitalized factories to participate in smart grids and for realizing resource circularity (see also [29]) and industrial symbiosis. Another important prerequisite for a future decoupling is referred to in [55] where potentials for a better harmonization of supply and demand between companies are stated. Yet, it remains vague under which circumstances and to what extent efficiency gains can be expected. Equally, the texts analyzed lack a more detailed contribution to the decoupling of growth and resource efficiency based on research findings. None of the publications has addressed changes to consumption patterns potentially induced by Industry 4.0.

Targets 8.9, 8.10, 8.a. and 8.b. were considered irrelevant for this analysis by the authors, as they are not linked directly to the concept of Industry 4.0.

3.2 SDG 9: build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

With the ambition of improving productivity, growth and employment as well as efficiency, Goal 9 has overlaps with Goal 8 albeit with a focus on the industrial sector and the inclusion of developing and least developed countries. These overlaps result in a partial redundancy of relevant text fragments (see also Sect. 4). A total of 58 text fragments are referring to topics related to SDG 9, where the target most addressed is target 9.4 (see Fig. 4). The targets of SDG 9 relate to economic (9.3), ecological (9.4), social (9.c), and socio-economic (9.2) topics.

12 text fragments refer to the topics mentioned in target 9.2, which calls for an inclusive and sustainable industrialization where the share of industrial employment is raised particularly in less-developed economies. In line with the contents described in Goal 8 authors expect an "*accelerated growth in productivity"* [32] and positive effects on industrial development since Industry 4.0 will allow *"faster, more flexible, and more efficient processes to produce higher-quality goods at reduced costs"* [30]. This,*"in turn will increase manufacturing productivity, shift economics, foster industrial growth and modify the profile of the workforce—ultimately changing the competitiveness of companies and regions"* [30]. Consequently, authors expect digitalization to support industrial growth whereas it is not clear which regions or countries will benefit from this growth expectations and improved competitiveness. As stated in the context of SDG 8, only one paper identifies new opportunities for non-industrialized countries through the virtualization of supply chains and digital technologies such as additive manufacturing [33]. With respect to the sustainability of future industrialization, a number of digitally enabled approaches are mentioned, including smart grid technology to supply smart factories with a higher share of renewable energy, as well as circularity and sustainable process design [41]. Gabriel and Pessl

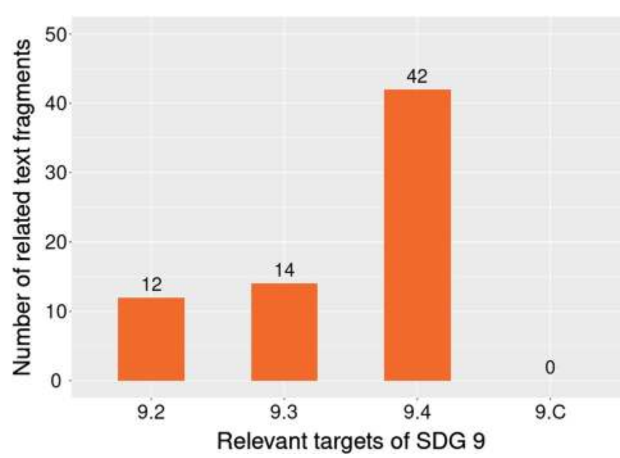

Fig. 4 Number of analyzed text fragments relating to the relevant targets of SDG 9 respectively

[29] request environmental and social impacts to be improved to *"ensure durable competitiveness "*. The former should be supported through a continuous monitoring, management and optimization of energy and material consumption over the entire value network [29]. The goal of raising the share of employment in industry has already been discussed in targets 8.3. and 8.5. Authors are primarily describing the significant changes in *"[…] job content, work processes, work environment and the required skills"* [29] promoting for example *"the idea of workers that increasingly will focus on creative, innovative and communicative activities"* [46]. There is also an emphasis on future requirements and qualification of workers in the literature, e.g. that *"technological innovations will continue to alter products and services and will therefore require workforces to continuously develop new knowledge and capabilities "* [45] and the transformation into human–computer cooperation will *"necessitate new qualifications for employees in manufacturing environments"* [45]. This only leaves room for speculations whether Industry 4.0 will create jobs and contribute to target 9.2. Meanwhile, the expected changing requirements of future jobs in Industry 4.0 emphasize the need *"for inclusive and equitable quality education and promote lifelong learning opportunities for all"* as called for in SDG 4.

The contents of target 9.3 ask for the integration of small and medium-sized enterprises (SMEs), especially from developing countries, into value chains and markets. These contents are addressed by 14 text fragments. While no paper refers to impacts on the also requested financial services, some text fragments refer to changing value chains and opportunities for SMEs due to digitalization. Zhong et al. identify the improved flow of information through digital interconnectedness and the cloud manufacturing concept as new opportunities for small-scale enterprises to enter manufacturing value chains [43]. Some publications argue these supply networks will become more flexible [29, 33, 34], while new digital technologies enabling cost-efficient batch size one production will reduce entrance barriers for SMEs [29]. An exemplary statement is *"[e]specially for SMEs Industry 4.0 entails USPs in international competition like lot size one, rapid response to customer, high quality and flexibility"* [29]. Xu et al. claim the same effect due to an increased usage of service oriented architectures [37], while according to Oesterreich and Teuteberg the major cause for this effect will be an improved horizontal integration of value networks [34]. As described for target 9.2 already, Li sees improved chances to participate in these virtual value chains for companies in emerging economies [33].

Target 9.4 demands to upgrade infrastructure and retrofit industries to make them more sustainable. 42 text fragments relate to this target. The majority of those refer to the topic of improving resource efficiency through Industry 4.0 technologies as has been extensively described for target 8.4 further above. The remaining text fragments address environmentally sound technologies and processes which have been explained for target 9.2. Upgrading the intraorganizational ICT infrastructure while also combining *"IoT technology with advanced machine learning algorithms"* to optimize the energy consumption of companies was suggested in [37]. Only one publication explicitly suggests retrofitting as *"an easy and cost-efficient way of upgrading existing manufacturing equipment"* in order to enable Industry 4.0 processes [41].

Even though target 9.c can be considered remotely relevant to the concept Industry 4.0, none of the papers covered by this analysis, was referring to it. Targets 9.1, 9.5, 9.a and 9.b have been considered as irrelevant to the concepts of Industry 4.0 by the authors and where not analyzed for that reason.

3.3 SDG 12: ensure sustainable consumption and production patterns

A total of 54 text fragments are referring to topics related to SDG 12, where the target most addressed is target 12.2 (see Fig. 5). The targets of SDG 12 relate to ecological (12.2, 12.5), socio-ecological (12.4) and a combination of social & economic & ecological (12.6) topics.

With respect to SDG 12 target 12.2 is the one most often referred to in our body of analyzed literature. 38 text fragments relate to this target. As it is focusing on the management and efficient use of resources, we refer to our descriptions regarding the issue of resource efficiency provided for target 8.4 and the optimized management of energy and material consumption described for target 9.2. Lasi et al. also emphasize that Corporate Social Responsibility is an essential approach for achieving sustainable management practices [3].

Target 12.4 is focusing on the management of chemicals and wastes. A number of publications suggest that Industry 4.0 will help to reduce the volume of waste [47, 48], pollutants [56] and emissions [29] induced by manufacturing processes. In order to achieve this goal Theorin et al. demand that future manufacturing systems need to be designed and optimized for such a purpose [48]. According to Gabriel and Pessl, 3D printing is one of these digital technologies, with the advantage of producing less waste than their conventional alternatives [29]. Stock and Seliger suggest that Industry 4.0 could enable an *"efficient coordination of the product, material, energy, and water flows throughout the product life cycles as well as between different factories"* [41] thereby additionally strengthening the concept of industrial symbiosis, where unused outputs by one company can be used as resource input for another company.

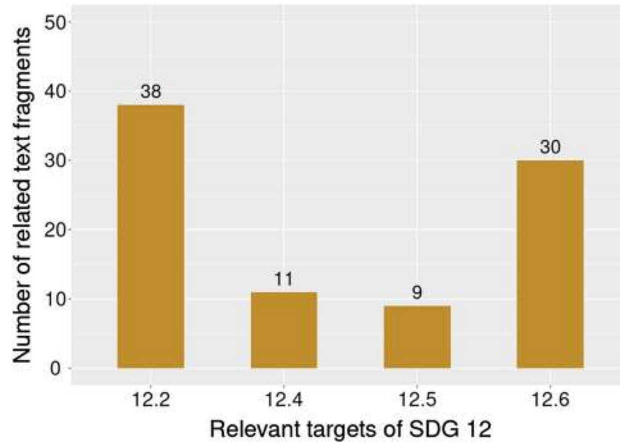

Fig. 5 Number of analyzed text fragments relating to the relevant targets of SDG 12 respectively

Target 12.5 is also addressing waste reduction like target 12.4. Additionally, it is focusing on recycling and reuse. Stock and Seliger suggest to use digital identification solutions being one integral part of the concept Industry 4.0 for material recovering [41]. In that manner, according to Gabriel and Pessl,*"even the most complex technical devices can be decomposed into its components at low cost and, subsequently, disposed or recycled"* [29]. With regard to waste prevention, retrofitting is mentioned as a basic solution to avoid having to buy new machinery [41], while one paper claims*"the ability to provide more individual or even products […] may reduce the number of product returns"* [57].

Target 12.6 is rather broadly demanding more sustainable practices and to integrate sustainability information into their reporting procedures. We have graded many of the approaches presented for previous targets under this term, such as Corporate Social Responsibility (target 12.2), practices for an efficient management of energy and material (targets 8.4 and 9.2) or their recycling and reuse (target 12.5). The strengthened role of sustainability reporting, which is also demanded by this target, is not explicitly addressed by any paper. Only one text fragments is indirectly referring to sustainability reporting requesting to widen the practice of Corporate Social Responsibility [3].

SDG 12 contains the biggest number of targets which occur to be not directly relevant for the Industry 4.0 concept. For that reason, we have not included 7 of its targets in our analysis, namely 12.1, 12.3, 12.7, 12.8, 12.a, 12.b and 12.c.

3.4 Main findings

Table 2 provides a quantitative overview of the number of text fragments (TF) and the sustainability dimensions they refer to. In order to demonstrate how many of those text fragments have been providing evidence for or at least references to their respective claim (TF_{evi}), we have calculated the evidence density ρ_{evi} per dimension of sustainability (Table 2):

$$\rho_{evi} = \frac{TF}{TF_{evi}}.$$

Since the concept of Industry 4.0 was developed in the Northern Hemisphere, it is also interesting from a SDG perspective to understand to what extent the concerns of emerging economies are taken into account in the perception of the concept. For that reason, we have also calculated the emerging economy density ρ_{emerg}, where TF_{emerg} stands for the number of text fragments explicitly addressing emerging economies:

Table 2 Number of relating text fragments per dimension of sustainability

Mapping of target to dimensions of sustainability	Number of text fragments (TF)	Emerging economy density ρ_{emerg}	Evidence density ρ_{evi}
Economic (8.1, 8.2, 9.3)	58	3.4%	5.2%
Social (8.5, 8.6, 8.7, 8.8, 9.c)	55	0.0%	1.8%
Ecological (9.4, 12.2, 12.5)	47	0.0%	4.3%
Social & economic (8.3, 9.2)	67	3.0%	3.0%
Social & ecological (12.4)	11	0.0%	0.0%
Economic & ecological (8.4)	39	0.0%	5.1%
Social & ecological & economic (12.6)	30	0.0%	6.7%

$$\rho_{\text{emerg}} = \frac{\text{TF}}{\text{TF}_{\text{emerg}}}.$$

4 Discussion

A fundamental difficulty with the present analysis concerns the similarity between individual terms and contents that are used to describe some SDGs, their targets and the respective indicators. Thus, it is sometimes challenging to clearly distinguish which statements are to be assigned to which target. Two of these group of terms are mentioned here as examples: on the one hand there is *"sustainable industrialization"* (target 9.2) *"environmentally sound technologies and industrial processes"* (9.4) and *"sustainable practices"* (12.6) and on the other hand *"resource efficiency"* in target 8.4, *"resource-use efficiency"* (9.4) and *"efficient use of natural resources"* (12.2).

Three clusters of content can be derived from the accumulation of relevant text fragments per target: resource efficiency, future labor conditions and economic issues referring to growth or productivity.

Most text fragments are addressing a purely economic or socio-economic perspective (see Table 1). Many of these economic expectations are relating to productivity and growth, which is not surprising, as they are inherent in the history of the development of the Industry 4.0 concept. The concept Industry 4.0 was developed by acatech, the German National Academy of Science and Engineering, whose statutory mission according to its website is to *"provide advice on strategic engineering and technology policy issues to policymakers and the public*." The concept they have developed is consequently aimed primarily to promote growth and productivity in German industry. But the demands in SDG 8 and the central targets 8.1 and 8.2 go far beyond this national perspective. Target 8.1 clearly calls for a focus to be placed on the economic development of the least-developed countries. Only one paper takes up this idea in the context of Industry 4.0, indicating that this approach to increasing global justice is only very inadequately taken into account in the literature analyzed. This is not uncritical against the background of high political expectations [19, 21] and findings of recent studies. These predict that Industry 4.0 technologies will be less widespread and less widely used in low- and middle-income countries [58] and suggest that, for example, African countries are likely to benefit less from increasing levels of digitalization [59]. In the context of the Thai economy, one study urges that societal and economic risks should be considered when rolling out Industry 4.0 technologies in this national context [60].

For the considerations on the opportunities of non-industrialized countries, the opportunities for SMEs expressed in targets 8.3 and 9.3 are also relevant. Several opportunities are provided for these classes of companies in the analyzed body of literature. This is contrasting some recent publications, which state a number of barriers for SMEs with regard to integrating Industry 4.0 technologies into their manufacturing operations [61–63].

The social dimension is also prominently reflected in our analysis (see Table 1. Many publications articulate expectations related to changes in employment through Industry 4.0—therefore, the most hits in absolute terms were identified in the text fragments with reference to targets 8.3 and 8.5. It is, thus, the most prominently treated social aspect of our analysis. When it comes to the statements on future labor conditions, it is noticeable that there is a rather diffuse picture. With regard to the development of the number of jobs, this heterogeneous picture fits in well with the two poles in the existing literature: while some studies fear a considerable loss of jobs due to the increased use of digital technologies in industry [64–66], others assume a significantly lower effect [67, 68] or even a net increase in jobs [69, 70]. It is widely acknowledged in the scientific debate though that lower-skilled and older workers are most vulnerable and likely to be displaced through the introduction of more complex work processes. Only one publication in our analysis was referring to the latter aspect, even though suggesting the opposite effect [29].

In general, the statements on the future of work are also characterized by a lack of interdisciplinarity. Many technology-centered publications describe what future cooperation between humans and machines may look like, but they do not specify how different models would affect workers. In other publications, there is a lack of technical know-how to develop real scenarios and not only negotiate possible sustainability aspects on an abstract level. In this context, it is important to note that workers are able to adapt to new challenges and have agency [67]. In participatory work environments they can also actively shape the way in which new technologies are integrated into their work processes [9, 71, 72]. The effects of digital technologies on industrial employment also strongly depend on other national factors such as the respective social protection mechanisms as well as the structure and the educational level of the workforce [10, 66, 67, 73]. These important aspects have hardly been reflected in our studied body of literature.

The smallest number of text fragments relate to the ecological dimension of sustainability (see Table 1). From an ecological perspective, the issue of resource efficiency is most prominent in our analysis. The targets 8.4, 9.4 and 12.2 all focus on this topic, although they address different levels of action. While resource efficiency on the company level is part of target 9.4, targets 8.4 and 12.2 are addressing the level of national economies—interestingly with the exact same set of indicators referring to material consumption and material footprint per capita or per GDP. It is noticeable that many publications merely postulate expectations of improved resource efficiency without providing an explanation or empirical evidence (see Table 1). The frequent mention of this ecological aspect should therefore not be misinterpreted as implying that the increasing implementation of the Industry 4.0 concept will automatically lead to greater resource efficiency. There are some approaches in the literature where the use of Industry 4.0 technologies has led to more energy efficiency [74–77] or a more economical use of materials [78]. However, it can be stated that these implemented positive examples are the exception so far [79] and do not yet meet the high expectations associated with the Industry 4.0 concept in that regard [19–21].

Our analysis also identifies another important element in support of sustainable development, namely the threat of a widening digital divide between countries of the global North and South. Only very few text fragments are taking the concerns of emerging economies into account (see Table 1).

The validity of the results of our research is limited by a number of factors. One of these factors is given by the restrictive selection of the search string and the literature database. Although the decision in favor of Google Scholar was made consciously in order to additionally include relevant publications from non-scientific actors, other literature databases would probably have identified further relevant publications for the analysis. The same applies to opting for a broader search string, which we have consciously decided against as the central research question of our analysis was to analyze the currently established interpretation of the concept Industry 4.0 and its anticipated impacts on the SDGs. Another limitation can be seen in the quantitative evaluation of the hits per target. Due to the mentioned similarity of the contents of some indicators, possible assignments of individual text fragments cannot always be carried out selectively. This gave way to subjective factors with regard to the interpretation of individual text fragments by the authors. It must also be mentioned that the targets formulated by the UN and the indicators selected are not comprehensive enough to reliably achieve the goals formulated in the SDGs. For this reason, we may have missed or not considered particular sub-aspects in our analysis that are not directly associated with SDGs 8, 9 or 12, but can nonetheless contribute to achieving more sustainable development. Likewise, it would have been conceivable to choose other theoretical frameworks to operationalize the concept of sustainable development instead of the SDGs.

5 Conclusion and outlook

Industry 4.0 can only lead to a more sustainable development if the concept takes essential characteristics of sustainability into account. Thus, our analysis has investigated to what extent sustainability aspects are currently reflected in the most recognized articles about Industry 4.0.

In summary, it can be said that the description of the sustainability-relevant impacts of Industry 4.0 reflects many expectations and hopes but they are hardly ever based on empirical or other evidence. During the digital transformation of industry conflicts and dilemmas will likely occur between the ecological, economic and social dimensions of sustainability that will require painful compromises and trade-offs. Yet, many of these conflicts can be treated adequately if all relevant actors engage in a mutual process of co-designing objectives, rules and regulations for a governance structure in line with the normative goals of sustainability. Such processes should be oriented towards the common good and be based on scientific evidence [7]. Practitioners need to be integral members of these discourses, so that actual challenges and best practices from corporate contexts are shared with other communities to enable mutual learning processes and the dangerously common myth of an increased ecological performance as an automatic consequence of digitalization can be deconstructed. The findings of such transdisciplinary interactions should be made available to the broader public to allow for mutual learning processes that support the transformation towards a more sustainable development.

Central expectations are focused around strengthening economic parameters such as growth and productivity through the digitalization of production. A certain objective is pursued, which is very much following traditional paths, even though Industry 4.0 has been introduced as an innovation and disruption to industrial production. However, this innovation relates almost exclusively to technological developments being applied in the existing contexts. Therefore, many descriptions draw a picture in which Industry 4.0 processes run exactly as before, just in a digital way. The transformation potentials associated with the Industry 4.0 concept that would also be necessary to help achieving the sustainability goals agreed in the SDGs and the Paris Climate Accord will not be realized in this way. Only if comprehensive sustainability considerations were integrated into the Industry 4.0 concept and included in its implementation, it would be possible to weigh up different design options which make an actual contribution to sustainable development. This is currently not the case.

In order to address these shortcomings, the political and public discourse about Industry 4.0 and its implications on sustainability need to be intensified. In some research communities, Industry 4.0 is still understood as a mere technical development, but research has to take on an interdisciplinary point of view to understand the complexity of social, environmental and technical interconnections that are immanent to the Industry 4.0 concept. This would require digging deeper than only hoping for efficiency gains as a "byproduct" of digitalization, while also systematically investigating potential risks of Industry 4.0 for a sustainable development.

It is striking that there is currently hardly any dedicated research dealing with the overlap between Industry 4.0 and the SDGs. This research would be important to help shape the research agenda and thus also the implementation of Industry 4.0 in companies. One possible approach for this would be to focus on a certain selection of particularly important indicators from SDGs 8, 9 and 12 (such as the indicators 8.5.2*"Unemployment rate, by sex, age and persons with disabilities"*, 9.4.1*"CO2 emission per unit of value added"* and 12.2.1 *"Material footprint, material footprint per capita, and material footprint per GDP"*) as focal but action-guiding orientations for a future design of Industry 4.0 implementations.

Publicly funded research schemes addressing Industry 4.0, especially those operating at the interface of science and industry, should include and equally balance chances and risks for a sustainable development. Policies should also aim at encouraging companies to think about the digital support of their sustainability management. To create flagship projects in companies could be one way to achieve that. Additionally, assisting small- and medium-sized enterprises with digital modernization, and designing digital products that actually reduce energy and material demand are major objectives for designing a sustainable digital future.

Opportunities and risks are closely intertwined and require informed and deliberate management decisions in order to be effective and favor sustainable development. Digital innovations will not per default increase sustainable practice; rather a professional technology assessment, a clear commitment to sustainability goals as expressed in the UN SDGs, and an inclusive decision-making style are required to promote sustainability within all three dimensions of sustainability. As an overarching task for the international community, efforts should also be intensified for all regions to ensure that the increasing implementation of the Industry 4.0 concept enables a globally equitable distribution of the opportunities offered by digitalization in the manufacturing industry.

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Declarations

Competing interests The authors declare no competing interests.

Appendix 1

See Table 3.

Table 3 List of publications included in the analysis ranked by their respective number of citations:

Authors	Year	Title	Publication	Citations	Excluded
Lee, J; Bagheri, B; Kao, H-A	2015	A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems	Manufacturing Letters	1183	
Brettel, M; Friederichsen, N; Keller, M; Rosenberg, M	2014	How Virtualization, Decentralization and Network Building Change the Manufacturing Landscape: An Industry 4.0 Perspective	International journal of mechanical, aerospace, industrial and mechatronics engineering	648	
Lasi, H; Fettke, P; Kemper, H-G; Feld, T; Hoffmann, M	2014	Industry 4.0	Business & Information Systems Engineering	637	
Lee, J; Kao, H-A; Yang, S	2014	Service Innovation and Smart Analytics for Industry 4.0 and Big Data Environment	Procedia CIRP	604	
Monostori, L	2014	Cyber-physical Production Systems: Roots, Expectations and R&D Challenges	Procedia CIRP	451	
Rüßmann, M; Lorenz, M; Gerbert, P; Waldner, M; Justus, J; Harnisch, M	2015	Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries	Boston Consulting Group Report	302	
Wang, S; Wan, J; Zhang, D; Li, D; Zhang, C	2016	Towards smart factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination	Computer Networks	274	
Jazdi, N	2014	Cyber physical systems in the context of Industry 4.0	2014 IEEE International Conference on Automation, Quality and Testing, Robotics	270	
Stock, T; Seliger, G	2016	Opportunities of Sustainable Manufacturing in Industry 4.0	Procedia CIRP	261	
Shrouf, F; Ordieres, J; Miragliotta, G	2014	Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm	2014 IEEE International Conference on Industrial Engineering and Engineering Management	216	
Gorecky, D; Schmitt, M; Loskyll, M; Zühlke, D	2014	Human–machine-interaction in the industry 4.0 era	2014 12th IEEE International Conference on Industrial Informatics	215	
Wollschlaeger, M; Sauter, T; Jasperneite, J	2017	The Future of Industrial Communication: Automation Networks in the Era of the Internet of Things and Industry 4.0	IEEE Industrial Electronics Magazine	212	
Weyer, S; Schmitt, M; Ohmer, M; Gorecky, D	2015	Towards Industry 4.0—Standardization as the crucial challenge for highly modular, multi-vendor production systems	IFAC-PapersOnLine	188	
Wan, J; Tang, S; Shu, Z; Li, D; Wang, S; Imran, M; Vasilakos, AV	2016	Software-Defined Industrial Internet of Things in the Context of Industry 4.0	IEEE Sensors Journal	184	
Lu, Y	2017	Industry 4.0: A survey on technologies, applications and open research issues	Journal of Industrial Information Integration	183	
Qin, J; Liu, Y; Grosvenor, R	2016	A Categorical Framework of Manufacturing for Industry 4.0 and Beyond	Procedia CIRP	164	
Kagermann, H	2015	Change Through Digitization—Value Creation in the Age of Industry 4.0	Management of Permanent Change	163	
Hofmann, E; Rüsch, M	2017	Industry 4.0 and the current status as well as future prospects on logistics	Computers in Industry	158	

Table 3 (continued)

Authors	Year	Title	Publication	Citations	Excluded
Schmidt, R; Möhring, M; Härting, R–C; Reichstein, C; Neumaier, P; Jozinović, P	2015	Industry 4.0—Potentials for Creating Smart Products: Empirical Research Results	Business Information Systems	155	
Roblek, V; Meško, M; Krapež, A	2016	A Complex View of Industry 4.0	SAGE Open	143	x
Liao, Y; Deschamps, F; Loures, EdFR; Ramos, LFP	2017	Past, present and future of Industry 4.0—a systematic literature review and research agenda proposal	International Journal of Production Research	142	
Kolberg, D; Zühlke, D	2015	Lean Automation enabled by Industry 4.0 Technologies	IFAC-PapersOnLine	140	
Schumacher, A; Erol, S; Sihn, W	2016	A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises	Procedia CIRP	138	
Zhou, K; Liu, T; Zhou, L	2015	Industry 4.0: Towards future industrial opportunities and challenges	2015 12th International Conference on Fuzzy Systems and Knowledge Discovery	134	
Oesterreich, TD; Teuteberg, F	2016	Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry	Computers in Industry	124	
Li, X; Li, D; Wan, J; Vasilakos, AV; Lai, C-F; Wang, S	2017	A review of industrial wireless networks in the context of Industry 4.0	Wireless Networks	123	
Gilchrist, A	2016	Industry 4.0: The Industrial Internet of Things	Monography	120	x
Ivanov, D; Dolgui, A; Sokolov, B; Werner, F; Ivanova, M	2016	A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory industry 4.0	International Journal of Production Research	118	x
Almada-Lobo, F	2016	The Industry 4.0 revolution and the future of Manufacturing Execution Systems (MES)	Journal of Innovation Management	105	
Zhong, RY; Xu, X; Klotz, E; Newman, ST	2017	Intelligent Manufacturing in the Context of Industry 4.0: A Review	Engineering	103	
Schlechtendahl, J; Keinert, M; Kretschmer, F; Lechler, A; Verl, A	2015	Making existing production systems Industry 4.0-ready	Production Engineering	89	
Erol, S; Jäger, A; Hold, P; Ott, K; Sihn, W	2016	Tangible Industry 4.0: A Scenario-Based Approach to Learning for the Future of Production	Procedia CIRP	88	
Faller, C; Feldmüller, D	2015	Industry 4.0 Learning Factory for regional SMEs	Procedia CIRP	80	
Baur, C; Wee, D	2015	Industry 4.0 is more than just a flashy catchphrase. A confluence of trends and technologies promises to reshape the way things are made	McKinsey & Company report	80	
Bagheri, B; Yang, S; Kao, H-A; Lee, J	2015	Cyber-physical Systems Architecture for Self-Aware Machines in Industry 4.0 Environment	IFAC-PapersOnLine	79	
Sanders, A; Elangeswaran, C; Wulfsberg, J	2016	Industry 4.0 implies lean manufacturing: research activities in industry 4.0 function as enablers for lean manufacturing	Journal of Industrial Engineering and Management	77	

Table 3 (continued)

Authors	Year	Title	Publication	Citations	Excluded
Theorin, A; Bengtsson, K; Provost, J; Lieder, M; Johnsson, C; Lundholm, T; Lennartson, B	2017	An event-driven manufacturing information system architecture for Industry 4.0	International Journal of Production Research	76	
Sommer, L	2015	Industrial revolution—industry 4.0: Are German manufacturing SMEs the first victims of this revolution?	Journal of Industrial Engineering and Management	73	
Mosterman, PJ.; Zander, J	2016	Industry 4.0 as a Cyber-Physical System study	Software & Systems Modeling	71	x
Varghese, A; Tandur, D	2014	Wireless requirements and challenges in Industry 4.0	2014 International Conference on Contemporary Computing and Informatics (IC3I)	69	
Vogel-Heuser, B; Hess, D	2016	Guest Editorial Industry 4.0–Prerequisites and Visions	IEEE Transactions on Automation Science and Engineering	67	
Liu, Y; Xu, X	2016	Industry 4.0 and Cloud Manufacturing: A Comparative Analysis	Journal of Manufacturing Science and Engineering	64	
Hecklau, F; Galeitzke, M; Flachs, S; Kohl, H	2016	Holistic Approach for Human Resource Management in Industry 4.0	Procedia CIRP	64	
Zezulka, F; Marcon, P; Vesely, I; Sajdl, O	2016	Industry 4.0—an Introduction in the phenomenon	IFAC-PapersOnLine	59	x
Zawadzki, P; Żywicki, K	2016	Smart Product Design and Production Control for Effective Mass Customization in the Industry 4.0 Concept	Management and Production Engineering Review	59	
Thames, L; Schaefer, D	2016	Software-defined Cloud Manufacturing for Industry 4.0	Procedia CIRP	59	
Gilchrist, A	2016	Introducing Industry 4.0	Chapter in Monography	57	x
Schuh, G; Gartzen, T; Rodenhauser, T; Marks, A	2015	Promoting Work-based Learning through INDUSTRY 4.0	Procedia CIRP	54	
Paelke, V	2014	Augmented reality in the smart factory: Supporting workers in an industry 4.0. environment	Proceedings of the 2014 IEEE Emerging Technology and Factory Automation (ETFA)	53	
Trappey, AJC; Trappey, CV; Hareesh Govindarajan, U; Chuang, AC; Sun, JJ	2017	A review of essential standards and patent landscapes for the Internet of Things: A key enabler for Industry 4.0	Advanced Engineering Informatics	52	
Li, L	2018	China's manufacturing locus in 2025: With a comparison of "Made-in-China 2025" and "Industry 4.0"	Technological Forecasting and Social Change	51	
Heng, S	2014	Industry 4.0: Upgrading of Germany's Industrial Capabilities on the Horizon	Deutsche Bank research report	50	
Xu, LD; Xu, EL; Li, L	2018	Industry 4.0: state of the art and future trends	International Journal of Production Research	44	
Bauer, W; Hämmerle, M; Schlund, S; Vocke, C	2015	Transforming to a Hyper-connected Society and Economy—Towards an "Industry 4.0"	Procedia Manufacturing	43	
Gabriel, M; Pessl, E	2016	Industry 4.0 and sustainability impacts: critical discussion of sustainability aspects with a special focus on future of work and ecological consequences	Annals of Faculty Engineering Hunedoara–International Journal of Engineering	30	

Appendix 2

See Table 4.

Table 4 Overview of SDGs 8, 9 and 12 and their respective targets

SDG	Targets
SDG 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	8.1 Sustain per capita economic growth in accordance with national circumstances, and in particular at least 7% per annum GDP growth in the least-developed countries
	8.2 Achieve higher levels of productivity of economies through diversification, technological upgrading and innovation, including through a focus on high value added and labor-intensive sectors
	8.3 Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage formalization and growth of micro-, small- and medium-sized enterprises including through access to financial services
	8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead
	8.5 By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value
	8.6 By 2020, substantially reduce the proportion of youth not in employment, education or training
	8.7 Take immediate and effective measures to eradicate forced labour, end modern slavery and human trafficking and secure the prohibition and elimination of the worst forms of child labour, including recruitment and use of child soldiers, and by 2025 end child labour in all its forms
	8.8 Protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment
	8.9 By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products
	8.10 Strengthen the capacity of domestic financial institutions to encourage and expand access to banking, insurance and financial services for all
	8.a Increase Aid for Trade support for developing countries, in particular least developed countries, including through the Enhanced Integrated Framework for Trade-Related Technical Assistance to Least Developed Countries
	8.b By 2020, develop and operationalize a global strategy for youth employment and implement the Global Jobs Pact of the International Labour Organization

Table 4 (continued)

SDG	Targets
SDG 9:Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation"	9.1 Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all
	9.2 Promote inclusive and sustainable industrialization and, by 2030, significantly raise industry's share of employment and gross domestic product, in line with national circumstances, and double its share in least developed countries
	9.3 Increase the access of small-scale industrial and other enterprises, in particular in developing countries, to financial services, including affordable credit, and their integration into value chains and markets
	9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities
	9.5 Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending
	9.a Facilitate sustainable and resilient infrastructure development in developing countries through enhanced financial, technological and technical support to African countries, least developed countries, landlocked developing countries and small island developing States
	9.b Support domestic technology development, research and innovation in developing countries, including by ensuring a conducive policy environment for, inter alia, industrial diversification and value addition to commodities
	9.c Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020

Table 4 (continued)

SDG	Targets
SDG 12: Ensure sustainable consumption and production patterns	12.1 Implement the 10-year framework of programmes on sustainable consumption and production, all countries taking action, with developed countries taking the lead, taking into account the development and capabilities of developing countries
	12.2 By 2030, achieve the sustainable management and efficient use of natural resources
	12.3 By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses
	12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment
	12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse
	12.6 Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle
	12.7 Promote public procurement practices that are sustainable, in accordance with national policies and priorities
	12.8 By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature
	12.a Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production
	12.b Develop and implement tools to monitor sustainable development impacts for sustainable tourism that creates jobs and promotes local culture and products
	12.c Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions, in accordance with national circumstances, including by restructuring taxation and phasing out those harmful subsidies, where they exist, to reflect their environmental impacts, taking fully into account the specific needs and conditions of developing countries and minimizing the possible adverse impacts on their development in a manner that protects the poor and the affected communities

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