Risks and Opportunities of Industry 4.0 for Corporate Sustainability

Abstract. Industry 4.0: digital technologies are changing the way industrial production works. This digital informatization of industrial production opens up opportunities for business informatics to develop sociotechnical solutions that support companies in their transformation towards more sustainability. The main contribution of this paper is the presentation, contextualization and controversial discussion of approaches identified in the literature, where digital technologies might offer an opportunity to support corporate sustainability. As a result the paper presents approaches where Industry 4.0 technologies support corporate sustainability management on a general level, and more specifically improve resource efficiency or enable Big Data approaches in order support corporate environmental management.

Keywords: Industry 4.0, Corporate Sustainability, CSR, resource efficiency, Big Data

15th International Conference on Wirtschaftsinformatik,
March 08-11, 2020, Potsdam, Germany

https://doi.org/10.30844/wi_2020_x4-beier

1 Introduction

In recent years, digitalization has become ubiquitous in all areas of the economy and society. Currently information and communication technology (ICT) networks globally consume 1.2% of the total electricity grid supply [1] and digital technologies emit around 4% of global greenhouse gas emissions – with an ascending trend [2].

In the context of industrial production, digitalization is often associated with the term Industry 4.0, which has gained wide recognition since its establishment in 2011, both nationally and internationally. According to [3–6] the Industry 4.0 concept is based on processes in which both the manufacturing systems and the objects to be manufactured are interconnected with each other through ICT and continuously exchange data. The interacting manufacturing systems can be organized in a decentralized manner and are enabled to flexibly organize and optimize themselves through digital technologies and so-called cyber-physical systems [3–6]. Industry 4.0 thus stands for a fundamental transformation of the manufacturing industry, which is also taken up in countries such as China, USA, India and Japan indicating its global impact.

At the same time, industry has a significant impact on key sustainability parameters: according to the International Energy Agency, the sector accounted for 41.6% of global electricity and even 79.8% of final coal consumption in 2016. As actors with social responsibility, companies are also important for the transformation process towards sustainable development. But companies also have an intrinsic motivation to adapt their business operations towards more sustainability. Some of them are already forced to regularly report openly on their sustainability performance (e.g. big companies through the Directive 2014/95/EU of the European Union on Non-financial and Diversity Information). Their sustainability performance is also becoming a reputational factor in the decision making processes of on the one hand potential customers [7] (whose decisions directly affect the economic success) but on the other hand also of potential employees, who seek to give a meaning to their work [8]. In summary it can be said, that society as a whole but also the companies themselves are likely to benefit from their improved sustainability performance.

However, it is unclear whether and to what extent the emerging digitalization of industrial production promotes - or even hinders - the transition towards sustainability. Can digital technologies and the availability of huge amounts of data also enable companies and their employees to operate more sustainable e. g. by helping to design more environmentally friendly sociotechnical systems for corporate environments?

This paper seeks to provide an overview on the question how Industry 4.0 can help to harness currently untapped transformative potentials of sustainability management in companies and thereby contribute to a sustainable way of doing business through data-driven sociotechnical systems. The main contribution of this paper is the presentation, contextualization and controversial discussion of approaches identified in the literature, where Industry 4.0 technologies might offer an opportunity to support corporate sustainability.

https://doi.org/10.30844/wi_2020_x4-beier

Table 1. Framework for relevant topics, software classes and Industry 4.0 technologies in the context of Corporate Sustainability Management (CSM)

	CSM dimension… environmental	CSM dimension… social
relevant topics	• emissions	• human rights
	• resources (consumption & efficiency)	• working conditions (gender equality, health, safety…)
	• waste & recycling	• inclusion
	• biodiversity	• stakeholder integration
	• …	• …
software classes	• Corporate Social Responsibility	
	• Environmental and Social Management System	
	• Corporate Environmental Management	• …
Industry 4.0 technologies	• Big Data	
	• Cyber-Physical Systems	
	• Artifical Intelligence	
	• digital integration	
	• …	

In order to investigate the sociotechnical potentials the aforementioned Industry 4.0 technologies need to be analyzed in combination with the most relevant topics and IT systems in the context of Corporate Sustainability Management. Therefore **Table 1** provides a framework for distinguishing Industry 4.0 technologies as well as relevant topics and classes of software distinguished per environmental and social dimension. This paper is structured based on this framework. The next section introduces general approaches for corporate sustainability management through digitalization in industry derived from the literature and stakeholder interviews, while the subsequent, more specific sections are each build up on topical combinations from the framework picking up a technological issue and relate it either to a relevant topic or to a software class. The first such combination (highlighted in blue in **Table 1**) deals with the influence of Industry 4.0 technologies on resource efficiency (as one very relevant topic from the environmental dimension): Section 3 presents findings from a literature analysis as well as empirical results from an interview survey in China. Section 4 presents the findings from a literature analysis on the second combination (highlighted in yellow) and discusses how Big Data technologies can help to support Corporate Environmental Management (as a major software class for the environmental aspects that need to be covered in corporate sustainability management).

2 Corporate Sustainability Management

Corporate sustainability management (CSM) is a relevant instrument of sustainable business, as it allows for a holistic view of the sustainability performance of

https://doi.org/10.30844/wi_2020_x4-beier

companies. Thus, possible shifts in environmental or social problems can be detected and indicated including, at least to a certain extent, the effects of digitalization itself. Sustainability Management supports companies in integrating the concept of sustainable development into their own culture, strategy, structures and processes. Creating transparency with regard to corporate activities and decisions is a key criterion for sustainable corporate management. Openly practiced transparency of companies, for example in the form of sustainability reports, can support the involvement of stakeholders of the company and thereby help to reduce the risks of damaging its credibility and reputation.

Against the backdrop of raising environmental challenges as well as growing social disparities between industrialized and developing countries the conditions under which products are manufactured and distributed are attracting more and more attention of consumers. Consumers have different motives for purchasing a specific product. In addition to common criteria such as price, functionality, taste or outward appearance, aspects of environmental and social sustainability are increasingly important selection criteria for many consumers. In order to convince consumers of the advantages of a specific product, transparency through corporate sustainability management can be a suitable vehicle.

Various Industry 4.0 scenarios also promise more transparency with regard to production processes. They are based on the consistent interconnection and digital integration of all process levels between different locations of one or several companies in the value chain and over the entire product life cycle. This results in a far-reaching potential for sustainability management - if the resulting data were used and evaluated accordingly.

The structure of the framework shown in **Table 1** underlines the need to tackle the question how increased, data-informed transparency about production processes can be used for effective sustainability management from various disciplinary perspectives. From an information technology perspective, it is relevant how data about the ecological effects of products and processes are fed into corporate software systems (see also Section 4) and how more flexible forms of digitalized production can be optimized under sustainability criteria such as resource consumption (see also Section 3). The identification and involvement of relevant stakeholders is considered a necessary and important prerequisite for contributing to an effective and widely accepted sustainability management.

From a socio-scientific perspective, Industry 4.0 is opening up new information and exchange paths both within and between organizations but also with their stakeholders. As an example, it can facilitate the diffusion of resource efficiency innovations and standards between companies (and their suppliers). Digitization will also shape globalization, in which traditional e-commerce wholesale can also be opened up for small and medium-sized enterprises (SME). On potential risk in this regard is increased indirect resource consumption, for example in the logistics sector.

Transformative potentials of a digitally supported sustainability management unfold through a further dissemination and improvement of corporate sustainability management which in turn will contribute to improved corporate sustainability performance, strengthen new forms of stakeholder engagement, and enable new forms

https://doi.org/10.30844/wi_2020_x4-beier

of sustainability governance. This can be done, for example, through a feasible technical component that ultimately supports sustainability management, simplifies it, and enables a variety of measures that are not established today. Transformative potential also unfolds when (technical) support makes sustainability management interesting for companies that did not previously have sustainability management (for example, SME) in operation. In addition to technical solutions, transformative potentials also arise when communicative and participatory aspects of a changed organizational structure of companies are considered and shaped, such as the involvement of stakeholders and thus also changing the social discourse about sustainable (corporate) development, making it an issue that must be considered from a sociotechnical perspective. Another transformative aspect arises when, beyond the traditional path of sustainability management, potentials are identified that are conceivable only in a digitalized world.

Table 2. General risks and opportunities for CSM through Industry 4.0

Risks	Opportunities
Refusal of staff members to interact with digital technologies	Reduce manual efforts to feed data into corporate software systems
Worsened CO2 footprint through the resources necessary to set up und run Industry 4.0 technologies	More transparency regarding the sustainability performance
Exclusion from or “invisibility” in CSM of not-yet-digital partners	May facilitate the diffusion of resource efficiency innovations and standards
Indirect rebound effects e.g. through increased logistical efforts	Supports the involvement of and exchange with stakeholders

3 Resource Efficiency through Industry 4.0

With regard to Industry 4.0 high expectations are often expressed about the potential for more resource efficiency. In its implementation recommendations of 2013, the Industry 4.0 working group (which was initiated by the German government) promised a continuous improvement in resource productivity and efficiency as a result of digitized value-added processes. These expectations are also reflected in the most relevant international policy papers addressing the topic [9]. In 2017 a study under Chinese companies showed that the overwhelming majority of participants expected very high or high material and energy savings potentials through Industry 4.0 (see Figure 1) [10]. In a similar study under German companies about one third of participants were also attributing resource efficiency as a very important factor for strategic decision-making in the future: with 32.5% for material efficiency and 38.5% for energy efficiency [11]. The following paragraphs reflect on the approaches that

https://doi.org/10.30844/wi_2020_x4-beier

can be found in the literature to realize more resource efficiency through Industry 4.0 technologies.

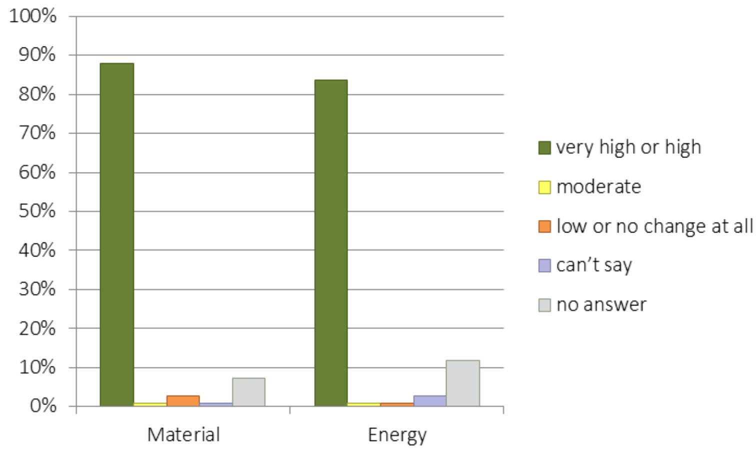

Figure 1: Expected resource savings potentials through Industry 4.0 in Chinese companies (in 2017)

Regarding the ecologically relevant resource efficiency potentials, the findings described in scientific literature are not unambiguous. In the energy sector, first promising approaches for more energy efficiency already exist. There, software solutions are developed that capture and aggregate data from digitalized production [12, 13], in order to allow for providing more transparency in terms of power consumption of the engaged manufacturing machines [14–16] while also enabling employees to flexibly steer production processes depending on their respective energy consumption as well as current electricity tariffs [10, 17]. A similar approach is to take advantage of the increased flexibility of production processes through Industry 4.0 to help reduce the volatility of renewable energy systems. This can be achieved by deliberately changing the timing of production processes in such a way that their energy requirements are greatest when renewable energy is highly available in the electricity market [18, 19]. This so-called demand response management requires a high degree of automated information technology coordination between electricity providers and consumers, which must be supported by user-friendly socio-technical systems in order to enable further dissemination within the industry. The general willingness to shift or postpone business processes, for example depending on the price of electricity, is currently not very established in companies [10]. The complexity of this coordination task is steadily increasing with the increasing number of decentralized renewable energy producers and consumers. Robotics is also working on energy efficiency measures. A very effective approach is to orchestrate a large fleet of robots through production control so that they do not perform every operation as quickly as possible (which is currently the default strategy in industry), but only as quickly as necessary [20]. This approach has led to energy consumption savings of up

https://doi.org/10.30844/wi_2020_x4-beier

to 30% and a reduction of peak-power up to 60% in a corporate setting from the automotive industry [21]. This is particularly relevant with regard to Industry 4.0, since, on the one hand, the number of robots operating globally is steadily increasing and, on the other hand, the temporal timing of production processes is becoming more flexible due to digital control mechanisms.
On the material efficiency side, only a few research approaches are currently identifiable. By using modern production technologies, such as 3D printing, raw or preprocessed materials can be used more sparingly [22, 23]. In the production of products with small batch-size, with particularly complex geometries, or in prototyping, digitalized processes can replace the more traditional material-intensive processes. However, these categories of products are expected to represent only marginal market shares in the foreseeable future, which is why the material savings potentials of Industry 4.0 are quantitatively rather negligible so far.
However, the savings potentials described above are offset by considerable additional expenditure of resources in the implementation of Industry 4.0. For example, all manufacturing systems involved in production must be retrofitted or completely replaced by modern systems in order to facilitate data collection and transfer. The German Mineral Resources Agency expects that the demand, driven by technological change, for the metals lithium, dysprosium / terbium, rhenium will increase significantly. Their demand could reach well over twice the current primary production volumes [24]. If manufacturing systems are designed to allow for flexibility and modularity, data transmission will probably be realized via wireless technology, which in turn is significantly more energy intensive than traditional wire-based transmission. The collected data must also be managed on servers that require cooling and already account for about 2% of global electricity consumption [25].

Table 3. Risks and opportunities for resource efficiency through Industry 4.0

Risks	Opportunities
High discrepancy between expectations and scientifically proven savings potentials	Flexibility to steer processes depending on their respective energy consumption and current electricity tariffs
Additional expenditure of resources for the implementation of Industry 4.0 technologies	Orchestration of dynamic characteristics of large fleets of robots
Higher energy demand for data transmission and management/storage	More awareness and transparency in terms of power consumption

4 Big Data for CEM

Making business processes more sustainable is becoming increasingly important for companies. At the same time does the digital transformation also lead to a continuous rise of available data on industrial production processes [26], while companies seek for collecting and analyzing these data to improve the quality and efficiency of their

https://doi.org/10.30844/wi_2020_x4-beier

processes [27]. Big Data can be defined as “high-volume, high-velocity and/or high-variety information assets that demand cost-effective, innovative forms of information processing that enable enhanced insight, decision making and process automation” [28]. Corporate Environmental Management (CEM) on the other hand, has the purpose to continuously improve a company with regard to their environmental performance [29].

The potentials of Big Data to support CEM are hardly dealt with in the literature, yet. A study focusing on different organizations from different sectors (non-governmental organizations, governments and companies) looks at potential connections between Big Data and CEM and sheds light on how difficult it is to implement the respective approaches [30]. However, it still concludes Big Data could be an important part of corporate sustainability, helping e. g. in measuring environmental performance of processes. A similar approach from an entrepreneurial background is presented in [31] where apart from potentials of Big Data in environmental performance measurement recent approaches in environmental management based on Big Data related technologies are presented.

In the context of implementing life cycle analysis (LCA) a major challenge is improving the availability of environmental data along the entire product life cycle [32]. Currently statistical mean value data is often used for that purpose [33]. However, Big Data could allow for collecting a multitude of real-time data from production processes as well as the usage phase of products. This idea is picked up by another study, which presents opportunities and challenges of Big Data for, by e.g. gathering heterogeneous data from different data sources [34]. Expert interviews with practitioners from the automotive sector support this idea and show that five different use cases could be beneficial for using Big Data to support CEM [35].

1. Improved creation of life cycle assessments: where Big Data helps companies to integrate data and predict user behavior from the entire product life cycle to better evaluate the actual environmental impact of their products.
2. Measuring energy consumption and increasing energy efficiency: Big Data helps to gather, connect and analyze all energy-relevant data from distributed sources within and outside a company (such as weather forecasts) in order to identify saving potentials and to establish a comprehensive and systemic energy management.
3. Measurement and reduction of emissions: when installing a network of sensors Big Data allows for identifying emission sources, mapping them by emission type and evaluating improvement measures.
4. Measurement and reduction of water consumption: Big Data helps to implement a real-time water consumption recording, identify losses and leakages, while analytics enable a company to identify saving potentials (focusing on wastewater and cause/effect analysis of implemented measures) and improve water consumption forecasts.
5. Optimization of Waste Management: Big Data helps to track the quantity and movements of waste more accurately, evaluate the performance of production

processes, to generate waste reports more automatically and to predict future waste outcomes to allow for a more efficient management of disposal measures.

Table 4. Risks and opportunities for CEM through Big Data

Risks	Opportunities
Energy-intensively collecting and managing vast amounts of data without deriving any environmental benefit	Helps in measuring and improving environmental performance of processes
Retrofitting machinery without deriving any environmental benefit	Improved creation of life cycle assessments
Heterogeneity of data from different data sources	Optimization of Waste Management

5 Discussion

Industry 4.0 is changing the way industrial production works. This digital informatization of industrial production opens up opportunities for business informatics to develop sociotechnical solutions that support companies in their transformation towards more sustainability. The main contribution of this paper is the presentation and controversial discussion of approaches identified in the literature, where digital technologies offer an opportunity to support corporate sustainability.

Promising approaches already exist with regard to Big Data and expert interviews underline their potential for five different use cases, were this technology can be the basis for sociotechnical solutions in business environments in order to enable organizations to gather, monitor and control environmental data. The further scientific investigation, prototypical implementation and evaluation of concrete applications from the mentioned use cases for Big Data could be a major contribution of business informatics helping to design sociotechnical systems that support the transformation of industrial businesses towards a more sustainable economy. Use case 2 even opens up synergetic potential to integrate corporate energy management solutions with more volatile renewable energy sources (see demand response in Section 3). However, to eventually untap this potential, a perspective on the data-relevant obstacles that are currently prevailing must be studied and the economic benefits of such approaches also from other branches should be clarified, before companies will start considering the implementation of such use cases.

With regard to resource efficiency there are clear potentials for energy and (to a lesser extent) material savings through the use of digitized technologies such as 3D printing or the orchestration of robots. There are also indications that fully digitally interconnected production systems require more energy and raw materials than their conventional predecessors. This is mainly due to installation and operation of additional sensors, control units and additionally required hardware for data processing. Some of the raw materials necessary to produce this hardware, such as rare earth metals, bromine or lithium, need to be processed in an environmentally

https://doi.org/10.30844/wi_2020_x4-beier

harmful manner. This must be openly taken into consideration when evaluating the environmental implications of digitalizing production processes.

Sustainability Management supports companies in integrating the concept of sustainable development into their own culture, strategy, structures and processes. As described above, the Industry 4.0 concept is based on end-to-end integration and interconnection, continuous data exchange across the entire product lifecycle between all process levels of a company, across multiple sites and even across company boundaries. This leads to far-reaching potentials for a digitalized sustainability management, which go beyond the limits of technical product creation processes and can only be exploited when companies interpret their own role as actors in a societal context. These potentials and the risks also being associated with them must be analyzed and evaluated in a transdisciplinary process involving all relevant stakeholders.

6 Conclusion

The paper presented an overview on how Industry 4.0 technologies offer an opportunity to support corporate sustainability. It critically discussed approaches on a general level but also on two specific combinations of technologies and CSM related topics or software classes respectively.

The validity of the papers findings are limited on the one hand by the selective choice of subtopics presented Sections 3 (focusing only on resource efficiency) and 4 (focusing exclusively on Big Data and its role for CEM) and on the other hand by the chosen method which was mainly literature analysis. Further investigations on the matter should therefore provide more empirical findings and tackle additional subtopics from the framework presented in Table 1 to cover a broader spectrum of CSM subtopics and thereby allow for more generalizable conclusions.

Industry 4.0 is not a single technology, but a concept in which different production technologies, information and communication technologies and organizational aspects interact. Improvements of individual aspects do not necessarily allow conclusions to be drawn about the overall impacts. Therefore, systemic studies that cover an entire value chain are necessary to be able to reliably estimate the net effect in terms of energy and material savings. Examining the sustainability potential that arises in the context of corporate sustainability management offers a possible starting point here.

Whether and to what extent Industry 4.0 contributes to the environmental improvement of production is also a question of creative will. The potentials are undoubtedly given, but they do not develop by themselves, instead they must be consciously striven for. Therefore, modernization processes in the area of production require a co-management according to the criteria of process and resource efficiency. In addition to the idea of efficiency, Industry 4.0 can also improve the transparency and support the implementation of circular economy concepts ideally being integrated into innovative, corporate sociotechnical systems that support the transition towards a more sustainable economy.

https://doi.org/10.30844/wi_2020_x4-beier

7 Acknowledgements

This work was supported by the German Federal Ministry of Education and Research (grant number: 01UU1705A) as part of its funding initiative “Social-Ecological Research“.

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