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Julian M. Muller

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Short Paper

Müller, Julian M., Kufstein University of Applied Sciences, Kufstein, Austria, julian.mueller@fh-kufstein.ac.at

Abstract

The concept of Industry 4.0, internationally also often referred to as the Industrial Internet of Things, enables data-driven business models to be implemented in industrial value creation. Further, the concept of Industry 4.0 aims to generate sustainable value in industrial contexts. However, both concepts, Industry 4.0-enabled data-driven business models as well as sustainable business models in Industry 4.0, have scarcely been investigated in extant literature. Hence, this paper aims to contribute to the understanding of research at the intersection of three disciplines: 1) Industry 4.0, 2) data-based business models, and 3) sustainability. For this purpose, relevant concepts and interconnections are drawn based on extant literature in the respective field. Further, this paper presents a research agenda that presents several important aspects of data-based sustainable business models in the context of Industry 4.0. These include, among others, designing data-based value offers that are based on economic as well as social and ecological aspects. Another example are value capture or monetization mechanisms that combine economic and ecologically or socially sustainable perspectives into a potentially multi-sided business model. Finally, the paper presents a perspective on future research and potential challenges in the respective aspects of data-based sustainable business models in Industry 4.0.

Keywords: Industry 4.0, Industrial Internet of Things, Digital Transformation, Business model innovation, Sustainable business model, Sustainability

Introduction

The concept of Industry 4.0, internationally often referred to as the Industrial Internet of Things, relates to a fourth industrial revolution. This fourth industrial revolution is based on technological enablers, the Internet of Things and Cyber-Physical Systems, alongside advanced manufacturing technologies. Both enable digital horizontal and vertical interconnection and integration of industrial Value Creation (Kagermann et al., 2013; Lasi et al., 2014). Industry 4.0 has gained large interest in managerial practice and academic research throughout several research disciplines. While research on the technological enablers dominated the academic debate in the first years after the concept was introduced in 2011, business and management sciences, as well as social and sustainability disciplines are increasingly investigating the concept. However, the interconnection between those non-technical disciplines, business management, and sustainability research, in this case, is only beginning to emerge in comparison to isolated research fields (Birkel and Müller, 2021; Horváth and Szabó, 2019, Müller, Buliga and Voigt, 2018).

The topics of Industry 4.0 and sustainability are deeply interconnected. The original concept of Kagermann et al. (2013) defines sustainable industrial value creation at the core of the concept of Industry 4.0. Through transparency along the entire value chain and from production to product usage, several potentials of Industry 4.0 towards sustainability are unlocked, also pointing towards the concept of the Circular Economy (Birkel and Müller, 2021). For instance, the balancing of production loads and thus

While the concept of Industry 4.0 in conjunction with business model innovation attracts increasing attention (Müller, Buliga and Voigt, 2018), the same is true for merging the topics of Industry 4.0 and sustainability in research (Birkel and Müller, 2021). However, merging all three topics, Industry 4.0, business models, and sustainability, remains scarcely understood in extant literature (e.g., de Man and Strandhagen, 2017). Relating to the above-named potentials of Industry 4.0.

Background

Industry 4.0

The term of Industry 4.0, introduced as "Industrie 4.0" in 2011 by the German government, refers to a fourth industrial revolution. It follow the three previous industrial revolutions, the first industrial revolution based on steam power, the second based on electrification and mass production, and the third based on automation (Kagermann et al., 2013; Lasi et al., 2014). Industry 4.0 is based on two base technologies: Cyber-Physical Systems and the Internet of Things. Cyber-Physical Systems, based on sensors and virtualization technologies, enable to merge the physical and virtual worlds. The physical world is replicated and complemented in the virtual world, allowing for simulations and advanced analysis, also referred to as virtual twins. Further, data processing and analysis capabilities, and capabilities for communication and interaction are required. Those technological capabilities are enabled by the Internet of Things. Hence, the Industrial Internet of Things is a term often used as a partially overlapping concept or even synonym for Industry 4.0. Worldwide, comparable concepts to the German concept of Industry 4.0 exists, such as "Made in China 2025" or "Factories of the Future" in the European Union. Mostly, the term Industry 4.0 has spread throughout the world and is commonly used (Kagermann et al., 2013; Lasi et al., 2014).

Based on the technological foundations described above, Industry 4.0 aims for three central characteristics that enable several potentials, especially across supply chains and across the lifecycle of products: Horizontal integration, i.e., digitally-enabled interconnection across the supply chain, vertical interconnection, i.e. digitally-enabled interconnection across company functions, and end-to-end engineering, i.e., across the entire product lifecycle, from production and product usage to recycling (Kagermann et al., 2013; Lasi et al., 2014).

The technological foundations of Industry 4.0 allow, alongside economic potentials, also ecological and social benefits and challenges at the same time (Kagermann et al., 2013; Tseng et al., 2018). These include organizational change, effects on job profiles and tasks, but also new business models that are required in order to benefit from the concept of Industry 4.0 (Barata and Rupino Cunha, 2018; Birkel and Müller, 2021; Bordeleau and Felden, 2019; Matthiae and Richter, 2018).

Business Models in the context of Industry 4.0

Based on the characteristics of horizontal and vertical integration, Industry 4.0 enables the generation of Big Data across industrial supply chains, and across product lifecycles, i.e., between production and product usage. This data transparency unlocks several potentials, such as new, data-driven business models, based on data collection, transmission, and analytics. In contrast to existing business models or business model innovations, data-driven business model innovations within Industry 4.0 require the collection, sharing, and analysis of data as central pillars of value creation, value offer, and value capture (Frank et al., 2019; Ibarra, Ganzarain, and Igartua, 2018; Müller, Buliga and Voigt, 2018; Weking et al., 2018). Through the interconnection of entire supply chains or entire industrial ecosystems, platforms can be established that enable mutual sharing, analysis, and learning from data generated for all contributors and stakeholders (Schmidt et al., 2020; Veile et al., 2020). Likewise, questions about data transparency, data security, and data possession arise if data shall be shared across the supply chain, leading to doubts and fears of smaller suppliers towards increased dependency and transparency, thus losing negotiation power and being easier to replace (Müller, Veile and Voigt, 2020).

Most definitions or conceptualizations of business models refer to three central elements, value offer, value creation, and value capture (Chesbrough, 2010; Foss and Saebi, 2017): Value Offer refers to the products and services offered to the customer, value creation how those products and services are realized, also including suppliers and partners, and value capture how the value offer is monetized, i.e., how money is generated. These elements, and hence entire business models of industrial firms are expected to change significantly through data-driven business models within Industry 4.0 (Müller and Buliga, 2019; Müller, Buliga and Voigt, 2021).

Technologies, or in this case the technological enablers of Industry 4.0, cannot unfold their entire potentials if business models are not adapted accordingly (Baden-Fuller and Haefliger, 2013; Chesbrough, 2010; Foss and Saebi, 2017; Rachinger et al., 2019). Hence, the concept of business model innovation has gained increasing attention from scholars in the last years, the interconnection with Industry 4.0 has been investigated increasingly in the last years, but is still less developed than research on technological foundations of Industry 4.0 (Frank et al., 2019; Ibarra, Ganzarain, and Igartua, 2018; Müller, Buliga and Voigt, 2018; Weking et al., 2018).

Enhanced value offers, i.e., products and services, in the context of Industry 4.0 include the increase in overall system efficiency, energy savings, better capacity utilization and lower susceptibility to errors, reduced and predictable maintenance requirements, simplified condition monitoring, autonomous production control, and lower inventories. Those are often represented by products that are complemented by industrial services (Frank et al., 2019; Müller, Buliga and Voigt, 2018; Weking et al., 2018). This further requires adaptions in machinery, production equipment, and workers for value creation. Likewise, suppliers and partners require adaptions, such as increased data exchange and new forms of collaboration (Müller, Veile and Voigt, 2020; Schmidt et al., 2020; Veile et al., 2020).

Regarding new forms of value capture mechanisms, subscription models such as pay-per-use and pay-per-feature are described, where the customer only pays for the actual service requested (Müller and Buliga, 2019). A digitized and therefore simplified communication with customers results in reduced transaction costs that allow these data-based payment models that would otherwise be too costly or require too much effort for customers and providers (Kohtamäki et al., 2019; Leminen et al., 2019).

Sustainable Business Models

In contrast to traditional business models, sustainable business models do not primarily strive for economic success, but additionally or even equally intend to create ecological and social value. Hence, value offers must be developed further towards generating ecological and/or social value. Further, value creation must consider ecological aspects increasingly, while value capture mechanisms must be able to transform this additional value generated into revenue (Bocken, Boons and Baldassarre, 2019; Evans et al., 2017; Geissdoerfer, Vladimirova, and Evans, 2018; Joyce and Paquin, 2016; Yang et al., 2017). For firms, sustainable business models require balancing the three dimensions within the Triple Bottom Line, economical, ecological, and social aspects, which arises additional challenges for the respective firms (Cesinger, Vallaster and Müller, 2021).

Within Industry 4.0, sustainable business models can be expected to take a distinctive role, trying to merge economic rationales with the overall aim of Industry 4.0 to integrate ecological and social aspects. However, while Industry 4.0 in conjunction with business models of business model innovation has been investigated increasingly in the last years, the interconnection to sustainable business models is considerably less developed so far in research (Birkel and Müller, 2021; de Man and Strandhagen, 2017). In response, this paper attempts to contribute to better understand the nexus of Industry 4.0, data-driven business models, and sustainable business models, as described in the following section.

Requirements for data-based sustainable business models in the context of Industry 4.0

Specific characteristics of data-based sustainable business models

Extending Müller and Buliga (2019), Table 1 below shows characteristics for three archetypes for data-driven business models in the context of Industry 4.0, highlighting specific characteristics of sustainable data-driven business models.

Table 1. Archetypes for data-driven Business Models in Industry 4.0 and specific characteristics of sustainable data-driven business models (based on Müller & Buliga, 2019)

Archetype	Value Creation	Value Offer	Value Capture
Platform-based business models	Data collection and analysis across entire value chains or ecosystems, serving multiple customers.	Sharing data allows multiple stakeholders to optimize existing or uncover unknown potentials.	License, model, Subscription model, Pay-per-use
Platform-based sustainable business models	Comparable to platform-based business models, but also including environmental or social certifications or institutions.	Traceability, compliance with ethical, environmental, or social standards, transparency of certifications for all stakeholders.	Subscription fee, License, Public funding for platform or sustainability features
Use-based business models	Data collection and analysis is conducted constantly, but presentation and evaluation is specific.	Optimization and insights regarding existing processes when needed for customers.	Pay-per-use, Pay-per-feature
Use-based sustainable business models	Certifications or environmental standards are collected and monitored consistently, but only charged if needed (e.g., regulations, recycling specifications).	Availability of certifications, environmental standards or optimization when needed, that would be too costly to monitor constantly, e.g., for SMEs.	Pay-per-use, Pay-per- feature, Public funding for platform or sustainability features
Outcome-based business models	Data collection and analysis that is combined with specific, individual services and knowledge.	Services targeted for specific purposes, such as reducing downtime or improving quality, combined with services.	Pay-per-output, Pay for guaranteed results
Outcome-based sustainable business models	Collection of data that is available for optimization for all customers, but only charged when improvements are made.	Reduction of CO2 emissions, load and energy balancing across the supply chain. Product input resource and logistics process reductions.	Pay for improvements, State subsidies (e.g., CO2 pricing)

As illustrated in Table 1, sustainability features, such as certifications, specifications, or information for recycling are increasingly important for data-based sustainable business models. Likewise, making this information available for all stakeholders of a platform, supply chain or ecosystem is a value offer in the context of sustainability, which includes stakeholders that could not afford this on their own, e.g., SMEs. Further, optimizations such as CO2 reductions or optimization of energy and load balancing or logistics processes can be established. Referring to the concept of the Circular Economy, recycling information or information if a product can be reused based on usage data can be shared and made available across multiple stakeholders. Other examples include optimized logistics processes or products that can be optimized as data is available from data usage and can be used directly in production and product development for over-the-air optimizations. Further, data-driven sustainable business models can profit from state subsidies or regulations, such as CO2 pricing, as they make reductions possible and visible that can then be supported by public funding or require less CO2 pricing-related spending (Birkel and Müller, 2021; Kumar et al., 2020; Rahman et al, 2020; Tseng et al., 2018).

Therefore, the central pillars of Industry 4.0, vertical and horizontal integration, also enable several potentials that are mostly based on data transparency across multiple stakeholders that were not available before (Kagermann et al., 2013). However, establishing data transparency also leads to several challenges (e.g., Müller, Veile and Voigt, 2020), as described in the next section.

Challenges of data transparency in the context of data-based sustainable business models

Figure 1 below illustrates typical challenges of Industry 4.0 towards sustainability across the supply chain when considering horizontal and vertical interconnection.

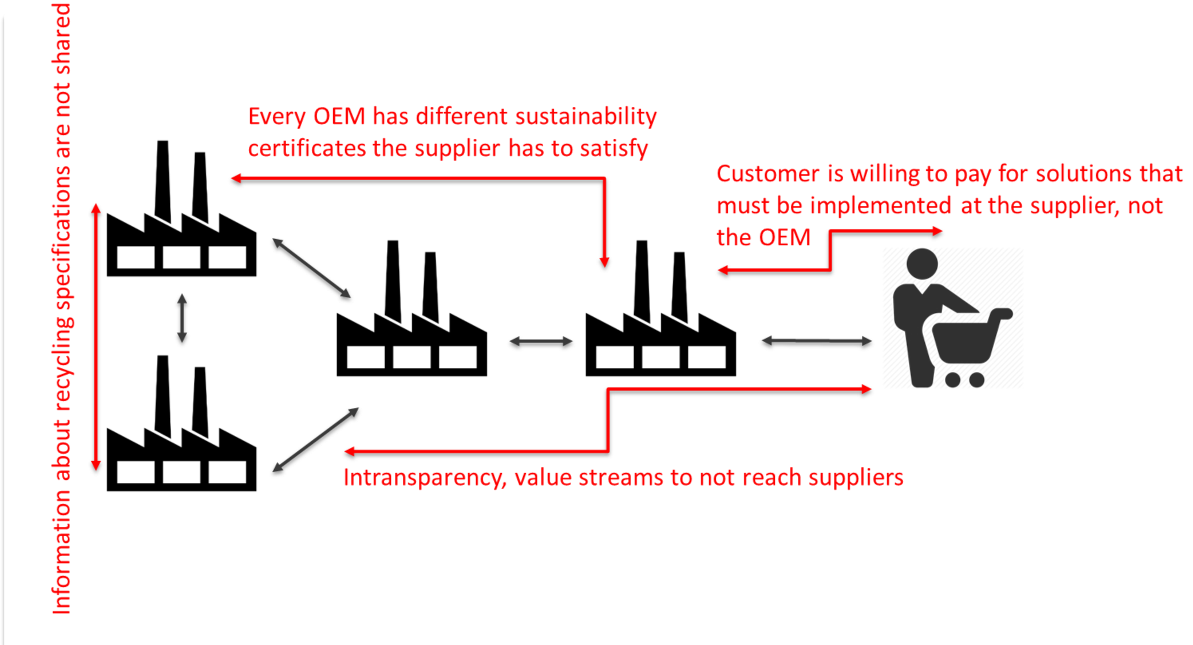

Figure 1. Illustrative challenges of sustainability in Industry 4.0

By requiring to share data across entire supply chains, platforms or even ecosystems, the question of how to generate such data transparency arises. Naturally, several stakeholders might night be willing to or even unable to supply the required data. This also includes challenges of standardization and interfaces (Müller, Veile and Voigt, 2020). Further, establishing revenue streams in data-based sustainable business models that reach the supplier providing certain sustainability features, not the direct supplier of a customer, is a challenging endeavor and requires to set up business models of supply chains or even ecosystems, not single actors (Kumar et al., 2020; Müller, Buliga and Voigt, 2021; Schmidt et al., 2020).

A research agenda for sustainable business models in Industry 4.0

Based on the characteristics and challenges of data-based sustainable business models presented in the previous section, several fields of action for future research are described that are necessary in addition to "classical" data-driven business models:

- **Defining value offers for sustainability**: Besides economic rationales of business models so far, sustainable business models require a clear value offer pointing towards ecological and social targets (e.g., Bocken, Boons and Baldassarre, 2019) and that can be measured by the data-driven nature of Industry 4.0.
- **Creating value capture mechanisms for sustainable value offers:** Sustainable business models will not succeed if they cannot be monetized for companies (e.g. Bocken, Boons and Baldassarre, 2019; Cesinger,). Hence, adequate value capture mechanisms must be defined for ecological and social value generation. One possibility in this regard is using (end)customers' willingness to pay and providing it to the sub-suppliers that might be accountable for ecological and social benefits. Further, state subsidies and funding can be integrated as a second value capture mechanism, as described below.
- **The role of state subsidies and mechanisms like CO2 pricing:** Sustainable business models must further capture state or public subsidies as a second revenue stream, alongside mechanisms like CO2 pricing or CO2 certificates (Birkel and Müller, 2021). Data transparency through Industry 4.0 can make benefits like CO2 reductions accountable and traceable, also across the entire supply chain
- **Understanding challenges of sustainable business models for established firms:** While economic potentials are easier to realize for companies, the specific challenges of realizing ecological and social value, requiring adequate value capture mechanisms and data transparency, among others, must be better understood. This is especially true for data transparency or monetization across the entire supply chain towards a Circular Economy (Kumar et al., 2020; Müller, Veile and Voigt, 2020).
- **Platforms for data-based sustainable business models:** Existing or new platforms could help to make information like recycling specifications or certificates available across entire supply chains or ecosystems (Rahman et al., 2019).
- **Sustainable start-ups and entrepreneurship:** Alongside established firms, the role of start-ups for data analysis and optimization, or as neutral agents for increasing and tracing ecological and social values could play an interesting additional role, also including non-profit firms (Cesinger, Vallaster and Müller, 2021).

Conclusion

This paper attempts to given an overview of conceptual interrelatedness, characteristics, and challenges of data-driven sustainable business models in the context of Industry 4.0. Further, a brief research agenda for data-driven sustainable business models is presented, highlighting possible avenues for future research.

Naturally, this paper can only give a first overview of those topics, that must be complemented and extended with empirical data and application examples. Nevertheless, connecting the topics of Industry 4.0, data-driven business models, and sustainable business models presents a huge potential to solve today's and tomorrow's challenges of sustainability.

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