

# Mitigation of intertemporal tensions in environmentally-sustainable manufacturing through Industry 4.0

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## Abstract

Manufacturing organizations face intertemporal choice problem, i.e., falling victim to pursuing short-term financial objectives or pursuing long-term environmental protection and social equity objective. Despite of the need to balance the present with the future, most sustainability research is centred on the tension between business and society, irrespective of time. We argue in this research that principles of Industry 4.0 could contribute to mitigating this intertemporal tension in sustainable manufacturing, moving towards a more sustainable society as well as world-class sustainable manufacturing.

**Keywords:** Sustainable Manufacturing, Industry 4.0, Intertemporal Tensions.

## Introduction

Much of the literature on corporate sustainability is centred around the tension between organizations and society, regardless of time (Smith and Lewis, 2011; Slawinski and Bansal, 2015). However, it is unclear how manufacturing organizations balance the short term and the long term sustainability objectives without restricting manufacturing organizations growth and freedom. Sarkis and Zhu (2018) posit that advances in manufacturing technology in the pursuit of manufacturing sustainability assumes achievement of organizational growth besides bringing about better cleaner production and rationalization of the use of resources that has a positive impact on environment and social welfare. In this realm, an emphasis is placed on the offerings of Industry 4.0 technologies, also known as smart manufacturing (de Sousa Jabbour, Jabbour, Foropon, *et al.*, 2018). Industry 4.0 is based on the establishment of smart factories, smart products and smart services embedded in an internet of things and of services (Lasi *et al.*, 2014, Stock and Seliger, 2016). It facilitates providing real time information on production, machines, and flow of components; integrating this information to help managers to make cost-effective decisions, monitor performance, and track parts and products (de Sousa Jabbour *et al.*, 2018). It is argued by Gouvea *et al.* (2017) that technological developments, such as those brought by Industry 4.0, is related to the sustainability of countries, and that technical advancements of manufacturers can

significantly enhance progress towards improvements in environmental quality (Song and Wang, 2016). For instance, de Sousa Jabbour et al. (2018) explained that using real-time data from manufacturing systems and suppliers can achieve high levels of efficient and economical use of resources such as materials, water, energy and products; as this leads to more sustainable manufacturing decision-making. Also, connecting machines, tools, devices, components, products, customers and logistics by means of internet, sensors, and RFID technologies would enable reconfiguration of these production system parts (Wang et al., 2016) based on customers' requirements, production parameters, and environmental performance (de Sousa Jabbour et al., 2018). In addition to these advantages, Industry 4.0 offers different sustainable approaches to cope with the social challenges of sustainability. Stock and Seliger (2016) asserted that Industry 4.0 adoption, first, increases the training efficiency of workers by combining new ICT technologies. Second, it increases intrinsic motivation and fosters creativity by establishing new cyber-physical based approaches of work organization and design, and, third, it increases extrinsic motivation by implementing individual incentive systems for the workers. Furthermore, the principles of Industry 4.0 enable instant data collection on customer requirements, usage and consumption patterns, thus allowing enhancement of service aspects of products, which will, in turn, improve customer satisfaction and well-being (de Sousa Jabbour et al., 2018). Based on this, it is argued in this paper that practices of Industry 4.0 support diverse temporal perspectives which encourage manufacturing organizations to juxtapose the short and long-term dimensions of sustainable manufacturing. Therefore, the following research question has been driving this research: RQ. How does Industry 4.0 principles and practices impact intertemporal tensions in sustainable manufacturing?

This paper is of a theoretical nature that is based on literature reviews of tensions of corporate sustainability, sustainable manufacturing, and Industry 4.0 topics. First, a literature review was conducted without focusing on one particular example or industry that was later followed by a more focused systematic review. Google Scholar was used to locate previous literature reviews conducted within the domain of Industry 4.0, tensions of sustainability, and sustainable manufacturing. Second, possible dimensions were inductively identified for analyzing relationships between the three main keywords used in this literature review process. This resulted in the identification of five different Industry 4.0 mechanisms to assist with mitigation of intertemporal tensions. However, this paper is further organized as follows. The next section presents the literature review conceptualizing intertemporal tensions in corporate sustainability. Next, principles of Industry 4.0 are characterized. This is followed by an attempt to link offerings of Industry 4.0 with intertemporal tensions of sustainable manufacturing. Finally, Industry 4.0 mechanisms for mitigating intertemporal tensions are explained and conclusions presented.

### **Intertemporal tensions in corporate sustainability**

According to der Byl and Slawinski (2015), intertemporal tensions in organizations is understood through prioritizing short term economic dimension of sustainability over the two other long term dimensions. According to authors, this has been detrimental to our understanding of corporate sustainability. This is due to the fact that instrumental logic neglects intertemporal tensions where social and environmental goals cannot be aligned with profit maximization targets (Smith and Lewis, 2011). Slawinski and Bansal (2015) uniquely defined corporate sustainability as “the ability of firms to respond to

their short-term financial needs without compromising their (or others') ability to meet future needs". Arising from this, Marginson and Mcaulay (2008) revealed that short-termism cannot be understood through organizational economic causes only; short-termism must be approached through a lens that includes individual and organizational level to advance organizational ability to mitigate its detrimental consequences for the long-term performance. Similarly, Hahn *et al.* (2015) make the case that short-termism, in corporate sustainability context, is caused by a mismatch between information available for managers to make sustainability decisions and information needed for those decisions. In other words, lack of complete information that lowers uncertainty about the future force managers to focus on sustainability aspects that are relevant in the short term. This would firmly suggest that mitigating intertemporal choice problem is possible through cutting-edge technologies that facilitate real time information on all aspect of the business (Marginson and Mcaulay, 2008; Hahn *et al.*, 2015). However, in response to this need, Similarly, Slawinski and Bansal (2015) suggest three mechanisms for temporal ambidexterity. The first mechanism is the collection of broad range of qualitative and quantitative data. The combination of such data provides information that is useful for decision-making processes and widens dialogue with organizational members on possibilities to juxtapose short-term objectives with long-term targets. The second mechanism is stakeholder engagement; starting an open dialogue with stakeholders allows organizations to intake different perspectives on sustainable issues and helps them learn about how best to attend these issues. The third mechanism occurs when organizations collaborate with each other. It is through this collaboration that organizations approach short and long-term business issues more holistically, therefore, providing better quality solutions for environment and society.

#### **Principles of Industry 4.0**

Stock and Seliger (2016) explain that the concept of Industry 4.0 is centred around three main dimensions of the manufacturing paradigm. First, the horizontal integration between organizations and organization-internal intelligent cross-linking and digitalization of value creation modules. This takes place throughout the entire value chain of a product life cycle and other related product life cycles. Second, smart digitalization and cross-linking of all phases of product life cycle from raw materials acquisitions to product end of life (i.e. end-to-end engineering). Third, vertical integration of cross-linking and digitalization of different hierarchical levels of value creation modules; from manufacturing cells, production lines, factories, and other associated value creation functions such as marketing and sales. According to de Sousa Jabbour, Jabbour, Foropon, *et al.* (2018), Industry 4.0 has four fundamental components through which it can be understood. These technological components are explained below.

*The internet of things technology* refers to a system where the physical devices (things) are equipped with embedded electronics such as software, sensors, RFID, tags, and controllers and connected to the internet to collect and exchange data (Burritt and Christ, 2016). In this sense, the internet of things constitutes an information technology infrastructure providing real-time connection of people, machines, devices, and information technology systems to solve complex business problems (Kiel *et al.*, 2017). As a result, large quantity of data, also known as big data (Zhong *et al.*, 2017), is generated and exchanged along the entire manufacturing value chains which can be

subsequently analysed to support and improve decision-making processes of organizations.

*Cyber-physical production systems* are defined by Deloitte (2015) as physical systems monitored and controlled by computer-based algorithms using virtual networks. They are operating in a self-organized (non-human) manner through means of artificial intelligence to continuously interchange data in real-time. Sensors, data processing units, and actuators are main components of cyber-physical production systems enabling real-time data transfer (de Sousa Jabbour, Jabbour, Filho, *et al.*, 2018).

*Cloud manufacturing* is an advanced manufacturing model using cloud computing technologies for enabling virtual on-demand network access to a shared pool of configurable manufacturing resources with minimal interaction with resources provider (Xu, 2012; Liu and Xu, 2016). In other words, it enables transformation of manufacturing resources into digitalised services that can be shared seamlessly through the support of virtualization and internet of things technologies (Zhong *et al.*, 2017).

*Additive manufacturing* is considered as an essential ingredient that is expected to increasingly be deployed in the Industry 4.0 movement (Stock and Seliger, 2016). It is a technology through which manufacturing of different components of products is possible without the need for a specialised manufacturing tools (de Sousa Jabbour, Jabbour, Filho, *et al.*, 2018). The virtue of additive manufacturing lies in the fact that it is able to produce physical parts based on digital information “piece-by-piece, line-by-line, surface-by-surface, or layer-by-layer” (Thompson *et al.*, 2016), thus, allowing the determination of components’ materials properties (Dilberoglu *et al.*, 2017).

### **Linking Industry 4.0 and intertemporal tensions of sustainable manufacturing**

From an environmental perspective, smart digitalization and cross-linking of the entire product life cycle (i.e. from raw materials acquisitions to product end of life) provide broad range of data with an immense opportunity for manufacturing organizations to understand patterns of usage and consumption (i.e. qualitative and quantitative information), which in turn can help organizations plan for the short-term (e.g. prioritising raw materials acquisitions processes and maintenance schedules) and long-term (e.g. improving product end-of-life reuse, remanufacturing, recycling, recovery and disposal). Also, cleaner production of products without generating waste or consuming unnecessary resources inherent in Industry 4.0 (de Sousa Jabbour, Jabbour, Foropon, *et al.*, 2018) create cost saving opportunities (i.e. short-term), enhance possibility of protecting environment with reduced depletion of resources (i.e. long-term), and improve intergenerational equity due to protecting interests of future generations (i.e. long-term) (Hahn *et al.*, 2018). Additionally, by analysing real-time data on energy consumption behaviour at production lines and machine level, energy data can be integrated in production management practices to improve energy efficiency of the factory (Shrouf, Ordieres and Miragliotta, 2014). This has a short-term objective of reducing energy consumption costs and contributes to long term reduced generation of GHG emissions. Manufacturing organizations, this way, can mitigate intertemporal tensions of corporate sustainability by creating the possibility to juxtapose short-term and long-term sustainability aspects. Furthermore, Industry 4.0 technologies seem to help juxtaposing the short and long-term issues of corporate sustainability by means of integrating value chains through real-time data analysis and sharing (de Sousa Jabbour,

Jabbour, Filho, *et al.*, 2018), thus, providing optimised solutions (Stock and Seliger, 2016). This virtue of Industry 4.0 is also matching Hahn's *et al.* (2015) acceptance strategy of dealing with temporal tensions, explained earlier, of adopting practices that are beneficial for short-term financial outcomes while also not detrimental to environmental and social issues. In this context, it is evident that Industry 4.0 offerings are beneficial in terms of short-term financial winnings and are fraught with practices that benefit environmental and social outcomes in the long run (Burritt and Christ, 2016; de Sousa Jabbour, Jabbour, Filho, *et al.*, 2018).

In fact, engagement of different stakeholders in Industry 4.0 such as customers, employees, suppliers, distributors, manufacturing equipment, and other organizations along value chain of products can play an essential role in achieving temporal ambidexterity. According to Slawinski and Bansal (2015), stakeholder engagement contributes to temporal ambidexterity by means of exposing an organization to plethora of information on diverse sustainability perspectives. Many of these stakeholders have strong ties with community representatives and other activists' groups who make their views listened to on different social and environmental impacts of businesses (Rivera, Muñoz and Moneva, 2017). This enables organizations to see broader range of timeframes of sustainability issues that help formulate better responses (Marginson and Mcaulay, 2008; Slawinski and Bansal, 2015). Another aspect that has been stressed in Industry 4.0 is the intelligent automation and cross-linking of organizational levels (Herrmann *et al.*, 2014; Schuh *et al.*, 2014; Stock and Seliger, 2016). Thus, the manufacturing jobs will entail more knowledge work and hard-to-plan tasks that require decentralised decision making processes (KIEL *et al.*, 2017). This is particularly important, since the establishment of Industry 4.0 technologies will bring about agility and connectivity to daily decision-making (de Sousa Jabbour, Jabbour, Foropon, *et al.*, 2018). This manufacturing organization's structural change would redefine traditional role of lower level employees to be responsible for achieving short-term operational aspects of the work and are not expected to deal with long-term strategic issues. Thus, the achievement of long-term objectives of sustainability is the responsibility of top management. This traditional notion of role separation is in line with Hahn's *et al.* (2015) "spatial separation strategy" of dealing with temporal tensions. However, we argue that cross-linking of organizational levels offered by Industry 4.0 technologies allow "spatial integration strategy". In this context, empowered lower level employees will be focused on monitoring and sense-making of the automated equipment (Schuh *et al.*, 2014; KIEL *et al.*, 2017). Different organizational levels, including top management, take part in the sense-making process through interpreting shared information to understand complex situations, and to assess the short-term and long-term consequences. This cooperative sense-making produce new knowledge on how to rapidly attend to short and long-term issues of corporate sustainability (Hofmann and Rüsçh, 2017; Zhong *et al.*, 2017). In addition, through increased digitised connectivity lower level employees, sustainability managers, accountants, and other senior managers would have access to real-time environmental management data where they could work together, in collaborative manner, on environmentally sound eco-efficient action for the long term (Burritt and Christ, 2016). Such offerings of Industry 4.0 broadened the solution space of issues of sustainable manufacturing, such that several simultaneous short-term and long-term considerations are achievable, thus juxtaposing present and future. Contributions of Industry 4.0 to mitigation of intertemporal tensions in corporate sustainability are depicted in Table 1.

Table 1 – Industry 4.0 mitigation mechanisms

Industry 4.0 mitigation mechanisms	Short-term economic benefits through:	Long-term environmental and social benefits through:
Cross-linking of entire product life cycle	<ul style="list-style-type: none"> <li>•Prioritising raw materials acquisitions processes and Improving maintenance schedules</li> </ul>	<ul style="list-style-type: none"> <li>•Improved product end-of-life reuse, remanufacturing, recycling, recovery and disposal</li> </ul>
Cleaner production	<ul style="list-style-type: none"> <li>• Reduced waste and consumption of unnecessary resources</li> </ul>	<ul style="list-style-type: none"> <li>•Reduced depletion of resources.</li> </ul>
Real-time data sharing and analysis	<ul style="list-style-type: none"> <li>•Enhanced energy efficiency of the factory</li> <li>•Track product deliveries and improved logistics routes</li> </ul>	<ul style="list-style-type: none"> <li>•Reduced generation of GHG emissions</li> </ul>
Stakeholder engagement	<ul style="list-style-type: none"> <li>•Rapid modifications to production and enhanced customer satisfaction</li> </ul>	<ul style="list-style-type: none"> <li>•Enhanced well-being of customers and society at large</li> </ul>
Cross-linking of organizational levels “Spatial integration”	<ul style="list-style-type: none"> <li>•Sense-making of the automated equipment by all organizational members.</li> </ul>	<ul style="list-style-type: none"> <li>•Reduced emission outputs</li> <li>• Formulation of environmentally sound eco-efficient action</li> </ul>

## Conclusions

This work shed the light on the unique potential of Industry 4.0 technologies to unlock juxtaposition of the short and long-term dimensions of sustainable manufacturing without restricting manufacturing organizations growth potential. To date, studies that explore the contributions of Industry 4.0 to sustainable manufacturing have been very limited. This paper is the first of its kind to analyze the role of Industry 4.0 in mitigating intertemporal tensions by enabling five different mechanisms of cross-linking of entire product life cycle, cleaner production, real-time data sharing and analysis, stakeholder engagement, and cross-linking of organizational level “spatial integration”.

Although this study points to Industry 4.0 as a significant savior for manufacturing sustainability (Sarkis and Zhu, 2018), it has some limitations which may pave the way for further research in the future. This paper is of a theoretical nature that is based on literature reviews of tensions of corporate sustainability, sustainable manufacturing, and Industry 4.0 topics. Therefore, the set of identified mechanisms might not be fully comprehensive. A question for future studies would be, therefore, under which conditions each one of these mechanisms would be more effective in tackling intertemporal issues of sustainable manufacturing. For this, it is strongly recommended that in-depth case studies be conducted using different methodological tools to further explore these mechanisms and their underlying aspects. Further, it would be relevant to include other domains in the analysis of the role of Industry 4.0 in mitigating intertemporal tensions of sustainable manufacturing. For example, exploring the role of green human resources management practices (Renwick, Redman and Maguire, 2013) in efficient application of different mitigation mechanisms of Industry 4.0. Another topical area is the investigation of impacts of information linkages and flow in Industry 4.0 on management of environmentally focused supply chains, and how this relates to intertemporal mitigation in manufacturing context. Overall, it is

evident in this paper that there is optimism that Industry 4.0-associated technologies hold numerous social and environmental sustainability benefits; beside those of financial benefits. Our suggested mitigation mechanisms thus help to provide substantive contributions to embracing intertemporal tensions of sustainable manufacturing.

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