Università degli Studi della Tuscia di Viterbo

Dipartimento di Dipartimento di Economia, Ingegneria, Società e Impresa - DEIM

Corso di Dottorato di Ricerca in

Economia, Management e Metodi Quantitativi - **XXXIII ciclo**

THE ROLE OF THE INDUSTRY 4.0 TECHNOLOGIES FOR ORGANIZATIONAL SUSTAINABILITY

SECS-P10 (SSD)

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A.A. 2019/2020

Acknowledgements

This manuscript represents the end of my PhD triennium. This experience has been hard and challenging. This result has been possible due to the people that supported me humanely and in the development of ideas and methodology for my dissertation.

Firstly, I infinitely thank my girlfriend Stefania that helped me overcome all my PhD concerns during this difficult path. Many thanks to my family, my mother Rita, and my father Dante Franco, that encouraged me to do the best I can. Thank you to Massimiliano that instil in me the love for science. Without your efforts, I would not probably have reached this achievement.

Then, I would like to thank some professors, postdoctoral researchers and PhD students that spent their time selflessly debating my ideas and helping me shape my PhD dissertation.

Thank you to my supervisor, Prof. Alessio Maria Braccini, for your guidance from the first to the last day of my PhD. Many thanks to all the professors that I encountered during conferences, visiting periods and PhD consortiums that discussed my dissertation ideas. and addressed my methodological doubts, especially Ilias Pappas, Peter Bednar, Hans Olav Egeland Omland, Øystein Sæbø, Alessandro Zardini, Eusebio Scornavacca, among others.

Thank you to my PhD colleagues and postdoctoral researchers for the long discussions on scientific articles, PhD difficulties and their encouragement, particularly The “Good” Frank Danielsen, Enrico Clementi, Jerome Sulbout, Giovanni Esposito, among others. They spurred me to go forward in my research.

Last but not least, thank you to my black crow that accompanied me during this experience.

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1 Introduction

Over the last years, manufacturing organizations face several challenges to maintain their competitive edge due to fierce competitors, demanding customers, and the need for sustainable production. (Porter & Heppelmann, 2014; World Manufacturing Foundation, 2018, 2020).

Manufacturers face increasing competitive pressure from worldwide competitors, particularly from developing country competitors. They sell similar quality products at a lower price because they pay fewer taxes than developing country organizations (Li, 2018). Moreover, they have lower staff cost, which reduces organizational costs. Hence, these organizations have a mark-up with lower prices (Porter & Heppelmann, 2014).

Moreover, customers desire products even more customized, both in the design and functionalities, to fulfil their needs in a better way (Porter & Heppelmann, 2015). Manufacturing organizations are unprepared to satisfy these requirements because they design traditional production to exploit the economy of scale and scope by producing a high quantity of similar products. Thus, manufacturing organisations have difficulty addressing this demand (Kagermann, Wolfgang, & Helbig, 2013; Lasi, Fettke, Feld, & Hoffman, 2014).

Furthermore, organizations have been considered responsible for multiple societal challenges, with social, environmental, and economic consequences (Porter & Kramer, 2019). The growing international attention on their environmental impacts, stricter environmental regulations and social justice are key factors that push organizations to change their way of operating. In particular, the manufacturing industry, the core industry in a national economy (Li, 2018; World Manufacturing Foundation, 2018), needs to change production processes because they are considered a resource and energy-demanding as well as labour-intensive (Ruggieri, Braccini, Poponi, & Mosconi, 2016). The manufacturing production currently damaged our planet, generating a proliferation of environmental issues over the last decades (Chen, Despeisse, & Johansson, 2020). According to the International Energy Agency (2015), the manufacturing industry globally contributes more than 35% of CO2 emissions and consumes nearly one-third of the energy consumed (IEA - International Energy Agency, 2015). This negative effect contributes to making the planet hotter accelerating climate change. And it also causes the pollution of natural resource – like water – which leads to significant health problems for people (Gleick, 2002).

Also, manufacturing organizations exploit human works for intensive hard-muscular and repetitive tasks in a work environment that are often unsafe – due to the presence of powders in the air, which makes the work unhealthy for workers (Bonekamp & Sure, 2015). Still, the increasing pressure of low-cost competitors negatively affects the manufacturing industry employees in developing countries who have already experienced a decline due to the computerizations of tasks (Frey & Osborne, 2017). The reduction of production may impose on the organizations a limitation of production turns, decreasing the industry workers. Thus, this consequence may increase the unemployment rates of developed countries (Manyika et al., 2017).

1.1 Digitalizing manufacturing: Industry 4.0

Therefore, the increasing economic competition and the pressure of environmental and societal issues impose manufacturing organizations to innovate production processes. Thus, organisations can maintain competitiveness and embrace sustainability goals within their business (Hart & Milstein, 2003). Some studies pointed out that digital transformation addresses these challenges (Deloitte, 2015; Pappas, Mikalef, Giannakos, Krogstie, & Lekakos, 2018). The digital transformation consists of adopting advanced information technology in organizations (IT) (Matt, Hess, & Benlian, 2015). The exploitation and integration of IT allow the organizations to reshape the entire business models, thus supporting the creation of novel forms of value for organizations (Mikalef, Pappas, Krogstie, & Pavlou, 2020). This progress and change in technology lead to a change in how organizations work and how their workers generate value and interact with each other (Pappas et al., 2018). New digital business models are more accurate and efficient. They go beyond the economic needs, address societal and grand challenges, and generate shared value that impacts the companies, organizations, consumers, and the public (Porter & Kramer, 2019).

Thus, several governments have encouraged the digital transformation of the manufacturing industry through industrial plans. In 2011, Germany was the first to start this initiative announcing the “Industrie 4.0” plan (Kagermann et al., 2013), and was followed by several governments of European nations, that translating the German title, promoted Industry 4.0 plans (Tirabeni, De Bernardi, Forliano, & Franco, 2019). Thus, Industry 4.0 is considered a synonym of digital transformation for the manufacturers (Blunck & Werthmann, 2017). In the meantime, manufacturing associations of the U.S. undertook the plan “Industrial Internet”, the Chinese government launched “Made in China 2025” and the Korean government “Smart manufacturing” (Kang et al., 2016).

These plans have as common traits the adoption of leading-edge digital technologies along the assembly line of manufacturing organizations, including Big Data, Robotics, Internet of Things and Cloud Manufacturing. And above all, the application of the concept of cyber-physical systems.

Cyber-physical systems describe the IT technological basis combined with the physical world, namely the connection of information technology with mechanical and electronic elements (Drath & Horch, 2014). These systems allow a higher level of automation through the horizontal and vertical integration of production systems driven by real-time data interchange and flexible manufacturing (Kagermann et al., 2013; Thoben, Wiesner, & Wuest, 2017). The vertical integration is internal to the organization and represents the integration of several units. Horizontal integration refers to the digital information sharing that facilitates collaboration among partners within a supply chain and customers (Kagermann et al., 2013; Julian Marius Müller, Buliga, & Voigt, 2018).

Thus, by increasing automation, cyber-physical systems increase control machinery in assembly lines (Hozdić, 2015). The way with which organizations use I40 technologies allows addressing problems – including lack of lubrication and machine degradations - on the assembly line without human interaction through autonomous machines (J. Lee, Bagheri, & Kao, 2015). Moreover, this innovation promises to shift the way of production from mass production towards the so-called mass customization (Fatorachian & Kazemi, 2018). Mass customization refers to a production method that allows creating predetermined products with some customizations. It is adverse to the mass production – the current orientation of manufacturing production method – that aims at producing similar products at lower prices by exploiting economies of scale and scope (Kang et al., 2016; Zawadzki & Zywicki, 2016). Thus, the adoption of Industry 4.0 technologies allows meeting individual customers' needs and serving the market in a more desirably way (Kagermann et al., 2013).

The adoption of Industry 4.0 technologies promises to deliver sustainable value for organizations (Kiel, Muller, Arnold, & Voigt, 2017; Julian M. Müller, 2020). Industry 4.0 technologies support the organisation's economic growth and jointly address sustainability issues (Kamble, Gunasekaran, & Gawankar, 2018). Thus, manufacturing organizations can address their current challenges and maintain their competitive edge.

1.2 The triple bottom line of sustainability

Sustainability is a multidimensional framework that the "Triple Bottom Line" holistically considers (Elkington, 1997). The triple bottom line is composed of three dimensions:

- Economic Dimension: it refers to the impact of the organization's business practices on the economic system, and it represents the organizational attitude to create value and balance costs and revenues in the production and distribution of goods and services (Alhaddi, 2015).

- Environmental Dimension: it focused on the compatibility between the trend of use and renewal of resources in nature. This dimension manifests in the organizational attitude of consuming just the natural resources that can be reproduced from nature and producing emissions that can be absorbed naturally by the existing ecosystem (Alhaddi, 2015).
- Social Dimension: it refers to the organizational attitude to preserve and develop the people and social capital of communities within which organizations operate to create value (Dyllick & Hockerts, 2002)

The triple bottom line is considered a holistic framework of sustainability because it extends the historical concept of sustainability, represented by only the environmental dimension with the inclusion of the social aspects (Hartmann, 2020).

According to the triple bottom line perspective, organizations deliver sustainable value when they support all three dimensions seeking a balance among economic benefits, environmentally-friendly action, and human and social capital development (Kiel et al., 2017).

1.3 Expected sustainable value of Industry 4.0

To explore how the adoption of Industry 4.0 technologies create the sustainable value, I conducted a literature review. Figure 1 graphically represents the purpose of my literature review.

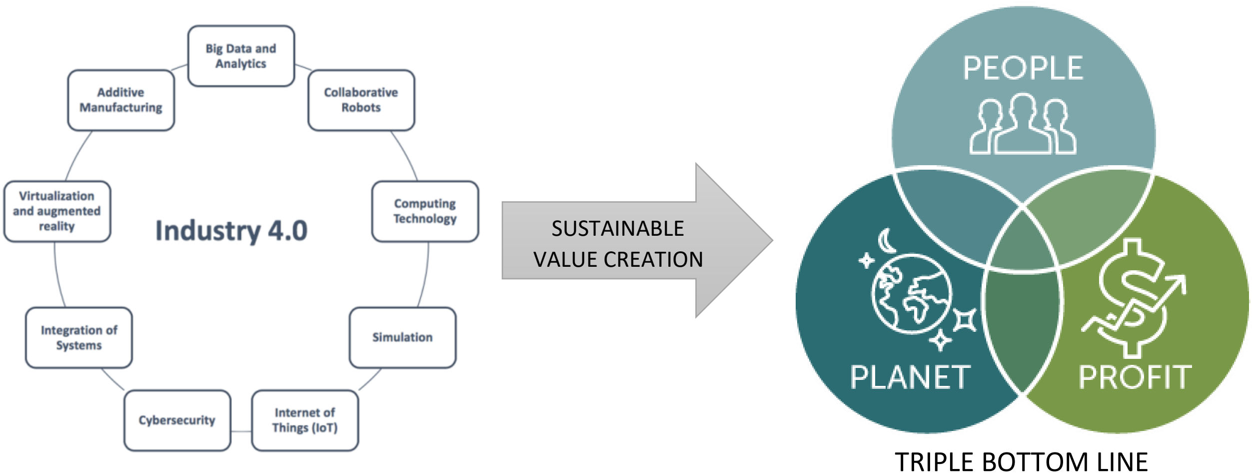

Figure 1 Sustainable Value Creation of Industry 4.0 technologies

The results show a scarcity of studies that illustrate the link between Industry 4.0 adoption and the three dimensions of the triple bottom line holistically. Industry 4.0 adoption supports satisfactory one dimension of the triple bottom line, particularly the economic and environmental dimensions, but not the three dimensions simultaneously (Ghadimi, Wang, & Lim, 2019; Kamble et al., 2018). Also, researchers paid little attention to how Industry 4.0 adoption supports the social dimension (Ghadimi et al., 2019; Kamble et al., 2018). Moreover, I found that achieving organizational sustainability by

Industry 4.0 technologies is challenging. These difficulties are due to the triple bottom line dimensions that provide an unclear solution for combining the partly conflictive goals of economic success, ecological balance, and social equity. As a result, these dimensions often conflict with each other (Kiel et al., 2017) and create tensions between the economic and the remaining dimensions.

There is a broad consensus on the potential economic benefits of adopting Industry 4.0 technologies, and the literature describes several technical and operational advantages. Industry 4.0 technologies increase the efficiency and flexibility of production processes, and deliver economic value in the form of higher productivity, higher-quality products (Fatorachian & Kazemi, 2018). Shin et al. 2014 show how big data analytics allows creating a predictive model that forecasts mechanic malfunction and maintains technical efficiency within the organization. Industry 4.0 adoption also contribute to increasing organisational logistics performance (Ben-Daya, Hassini, & Bahroun, 2017). Particularly, inventory management and warehouse management based on IoT applications increase the efficiency and effectiveness of the supply chain management, reducing the inventory inaccuracy and shorter time to markets (Ben-Daya et al., 2017; Cui, Deng, Liu, Zhang, & Xu, 2017; Yang et al., 2017).

The implementation of Industry 4.0 technologies contributes to addressing environmental issues by improved control of resource usage thanks to more accurate and granular information on energy and resource usage (Liang, Lu, Li, & Wang, 2018; Schulze et al., 2018). Industry 4.0 technologies also help decrease the number of damaged and defective products. Thus, Industry 4.0 adoption contributes to minimizing the waste in general and natural resource waste in production processes (Gabriel and Pessel 2016; Herrmann, Schmidt, Kurle, Blume, and Thiede 2014). Industry 4.0 adoption also supports the adoption of circular economy practices, particularly remanufacturing, providing a way to quickly find and reassemble products (Y. Zhang et al., 2018). The environmental dimension is also conflicting with the economic dimension, as environmentally sustainable products and processes are costly for companies, and customers tend not to be willing to pay more for cleaner products and services (Liu, Li, Zuo, Zhang, and Wang 2009; Liu and Bai 2014). Organisations address this tension with an Industry 4.0 adoption, which allows production only when there is a demand for these products and a production process that minimizes the use of resources, materials, energy, and the creations of wastes (Oláh et al., 2020).

Concerning the social dimensions, I found conflicting results due to tensions with the economic dimension of the triple bottom line. Few studies report the qualitative benefits of Industry 4.0 adoption. Industry 4.0 may improve workforce conditions by automating hard-muscular activities leaving for the workforce control tasks and problem-solving to manage unexpected technology issues (Gabriel & Pessel, 2016; Kagermann et al., 2013). Moreover, the way of producing in an Industry 4.0

assembly line may stimulate the workforce creativity as workers can contribute to the continuous optimization of the production process and development of new ideas for improved products, process, and services (Erol, Jäger, Hold, Ott, & Sihn, 2016; Shamim, Cang, Yu, & Li, 2016).

While most of the studies of Industry 4.0 technologies use a "technocentric" approach and consider the increasing automation as an enabler to support the economic dimension optimizing the production process and reducing the workforce; thus, Industry 4.0 adoption contributes to the disappearance of jobs (Kang et al., 2016). Industry 4.0 technologies may also degrade competencies, expertise, and know-how of blue and white-collar jobs because Industry 4.0 automates both operational and decision-making activities (Bonekamp & Sure, 2015; Nurazwa, Seman, & Shamsuddin, 2019). Industry 4.0 technologies also contribute to the impoverishment of the labour force because cyber-physical systems automated decision-making activities previously performed by workers. As a result, the workforce role is even more marginal within an organization (Liao, Deschamps, Loures, & Ramos, 2017; Nurazwa et al., 2019). And the workforce has fewer opportunities to undertake a career and remain stably employed in a manufacturing organisation (Chin, Jiao, & Jawahar, 2019; Chin & Liu, 2015).

1.4 Research gaps and questions

Therefore, the literature revealed a lack of studies that explain how organisations deploy Industry 4.0 technologies in a sustainable way.

The first literature gap indicates the lack of studies that report the sustainable value that Industry 4.0 technologies deliver on the three dimensions of the triple bottom line simultaneously. The review indicates studies illustrating the sustainable value of the innovation on one sustainability dimension but not on the three sustainability dimensions simultaneously (Fatorachian & Kazemi, 2018).

The second gap regards the relation between Industry 4.0 adoption and sustainability (Beier, Niehoff, & Xue, 2018; Kiron & Unruh, 2018; Machado, Winroth, & Ribeiro da Silva, 2020). Extant studies do not consider the multi-dimensional aspect of sustainability holistically, and Industry 4.0 adoption generates sustainable value on one dimension of the triple bottom line through the automation enabler. Therefore, this Industry 4.0 enabler, under the technocentric perspective, do not allow supporting the three dimensions of the triple bottom line simultaneously (Kamble et al., 2018).

The third gap regards the tension between the economic and social dimension that deserves further investigation because it impedes that Industry 4.0 adoption can support the social dimension, and therefore, to achieve sustainable value on the three dimensions of the triple bottom line.

Therefore, the main research question that summarizes the principal gap I found in the literature is: *"How do organizations deploy Industry 4.0 technologies in a sustainable way?"*

To answer the main research question, I propose three sub-questions:

Sub-question 1: *"What is the sustainable value that Industry 4.0 adoption delivers on three dimensions of the triple bottom line simultaneously in manufacturing organizations?"*

Sub-question 2: *"How does a manufacturing organization adopting Industry 4.0 support the three dimensions of the triple bottom line?"*

Sub-question 3: *"How does a manufacturing organization employ Industry 4.0 technologies to address the tensions between social and economic sustainability?"*

1.5 Research Methodology

To answer the research questions, I conducted a multiple case study analysis of five Italian manufacturing organizations that adopted Industry 4.0 technologies supporting the three dimensions of the triple bottom line. A multiple case study is recommended to investigate an emerging phenomenon, where few studies have been conducted (Yin, 2018). This methodology allows for cross-case comparisons to clarify whether the findings are idiosyncratic to a single case or apply to several cases (Yin 2018). Multiple case study analysis allows establishing patterns of relationships between constructs within and across cases with their underlying logical arguments by recursive cycling among the case data. The method involves selecting multiple cases, triangulating data during data collection, and analysing the data both within cases and across cases (Yin, 2018). For each case unit, I illustrated the adoption process (Markus, 2004) of Industry 4.0 technologies describing the traditional production process, the adoption process of Industry 4.0, and the novel Industry 4.0 production process. Then I report the sustainable value of the Industry 4.0 adoption.

1.6 Structure of the dissertation

The structure of the dissertation is as follows. In section 2, I introduce the theoretical framing of the study composed of: the Industry 4.0 initiative, the presentation of Industry 4.0 technologies, the concept of sustainability and the theoretical framework of the triple bottom line. In section 3, I report a literature review of the sustainable value creation of Industry 4.0, highlighting the state of the art and gaps of the research. In section 4, I describe the research design for the multiple case study, the case selection criteria, the protocol for data analysis and collection, and stating my philosophical assumption. In section 5, I present the evidence from multiple case studies illustrating the adoption process of Industry 4.0 technologies and the analysis for each case. In section 6, I detail the analysis findings showing the sustainable value creation on the entire triple bottom line by Industry 4.0 adoption, how these technologies create value and how the management address the tension between the social and economic dimension due to the Industry 4.0 automation. In section 7, I answer the three research sub-questions and discuss the implications for both researchers and managers. In section 8, I offer some conclusions.

2 Theoretical Framework

In this section, I illustrate the theoretical framework of the study. The work is framed in two separate literature streams. In section 2.1, I present the Industry 4.0 initiative. Since Industry 4.0 is an umbrella term that refers to various national industrial initiatives based on several advanced digital technologies for manufacturers, a comprehensive presentation is needed. In section 2.2, I describe the concept of sustainability which deserves an in-depth analysis because it is a multidimensional concept and evolved over the years. The current concept of sustainability embraces both the social and environmental aspects of organizations. In contrast, the traditional concept only includes the necessity to preserve the environment from organizations.

2.1 Industry 4.0

The term Industry 4.0 (I40) derives from the German term "Industrie 4.0" and was mentioned in public for the first time at the "Hannover trade fair" in 2011 in Germany (Kagermann et al., 2013). The following "Industry 4.0" industrial plan, set by the Ministry of Education and Research of Germany, aims to encourage the German manufacturing industry to prepare for the future of production and ensure the competitiveness for the manufacturing industry (Blunck & Werthmann, 2017).

In the meantime, the term I40 is also widely used across Europe as the governments of European counties started similar industrial initiatives inspired by the German governments (Conseil National de L'industrie, 2016; GOS-Foresight, 2013). Figure 2 illustrates the industrial initiatives of Europe. Other terms appearing along with I40 are the "Internet of Things" or the "Industrial Internet (of Things)", "Made in China 2025", "Smart manufacturing." These terms are also applied interchangeably with the notion I40 as they are the title of the U.S.A, China, and Korea's industrial plans, respectively (Evans & Annunziata, 2012; Kang et al.

Thus, the term I40 currently describes the digital transformation of the manufacturing industry. Each I40 plan acknowledges that traditional manufacturing methods are run through a digital transformation (Deloitte, 2015). It promotes the adoption of advanced digital technologies – including Big Data, Internet of Things, which I describe in the next chapters –to optimize and integrate the production process and improve organizational performance. The purchase of these technologies is encouraged by incentives and tax reductions (Evans & Annunziata, 2012; Kagermann et al., 2013; Kang et al., 2016).

Figure 2 Map of the Industry 4.0 initiatives undertaken in Europe[1]

Indeed, all these industrial plans aim at ensuring the competitiveness of the national manufacturing sector, which is considered the core industry in a nation's economy (Kagermann et al., 2013; Li, 2018). Over the last years, the sector has experienced a shift in the production way from mass production to mass customization (Fatorachian & Kazemi, 2018); that is, the market no longer requires a high quantity of low-cost products but high-quality products with customizations. Moreover, European and North American organizations face competitors from developing countries that produce reproductions of their goods at a lower price. These market changes imply that organizations need to respond to changes in customer demands quickly, and they have to be flexible and significantly reduce their operational costs. They have to redesign their process to produce highly customized and high-quality products to meet customers' need rather than produce a higher quantity of productions (Walter-Herrmann, 2014). Also, they need to be smart enough to act intelligently and autonomously (Fatorachian & Kazemi, 2018; Leitao, Colombo, & Karnouskos, 2016). To this end, organisations require a high level of digitization, automation, and extensive interconnections of production systems/machinery and enterprise systems (Fatorachian & Kazemi, 2018).

Thus, I40 initiatives want to fulfil this requirement by adopting and integrating the I40 technologies down the production process, enabling the real-time interconnection of products, production facilities, humans, and smart devices in a vertical and horizontal manner (Julian M. Müller, 2020).

[1] Industry 4.0 initiatives https://ec.europa.eu/futurium/en/content/digitising-european-industry-catalogue-initiatives retrieved: 28/09/2020

The vertical integration is internal to the organization. It refers to integrating several organizational units, including marketing and sales or technology development, by end-to-end digital integration of I40 technologies across different levels right up to the ERP level deliver the vertical integration (Kagermann et al., 2013). Vertical integration enables digital order processes and customer-specific product development, where the manufacturing system assures an automated transfer of data into integrated planning (Blunck & Werthmann, 2017). The vertical integration also allows for a flexible and reconfigurable production infrastructure adapted to each specific customer order or even changing market requirements. These capabilities are pivotal for manufacturers to remain competitive in highly volatile markets because they help reach fast and fault-free production (Stock & Seliger, 2016). Still, vertical integration allows the development of modularisation and reuse strategies in order to enable ad hoc networking and reconfigurability of intelligent manufacturing systems (Y. Zhang et al., 2018).

The horizontal integration represents the digital information sharing that facilitates collaboration among partners within a value chain, including the customer (Julian Marius Müller et al., 2018). This integration involves internal areas of an organization (e.g., purchasing, production, logistics), which are integrated with all value chain partners.

The horizontal integration characterizes the smart networking of cross-company and internal-company that digitalized the information flow of internal programmable logic controllers (PLCs) of organization and PLCs of its value chain (Stock & Seliger, 2016). The integration of the horizontal value chain optimizes the information flow and flow of goods from the customer to the organization and vice versa (Blunck & Werthmann, 2017). Thus, horizontal integration enables organizations to adapt constantly to new market changes by the automatic optimization of production processes among partners (Kagermann et al., 2013).

By achieving this technological integration, I40 adoption promises social, environmental, and economic outcomes for organizations thanks to the increasing automation. The production process automation improves the quantity produced and the quality of goods (Fatorachian & Kazemi, 2018). The automatic control of machinery allows for optimising energy used down the assembly line, enabling the organization to undertake constant energy savings (Liang et al., 2018). Still, the production process automation also impacts positively the workforce, which is not in charge of repetitive and hard-muscular tasks. Thus, workers can prolong their tenure as they conduct more mental activities (Kagermann et al., 2013).

2.1.1 Industry 4.0 technologies

I40 initiatives build on several advanced technologies that aim at ensuring the competitiveness of the manufacturing industry (Evans & Annunziata, 2012; Kagermann et al., 2013; Kang et al., 2016). In this paragraph, I present the fundamental technologies of the I40 initiative (de Sousa Jabbour, Jabbour, Foropon, & Filho, 2018; Kang et al., 2016). Figure 3 graphically summarizes the presented I40 technologies.

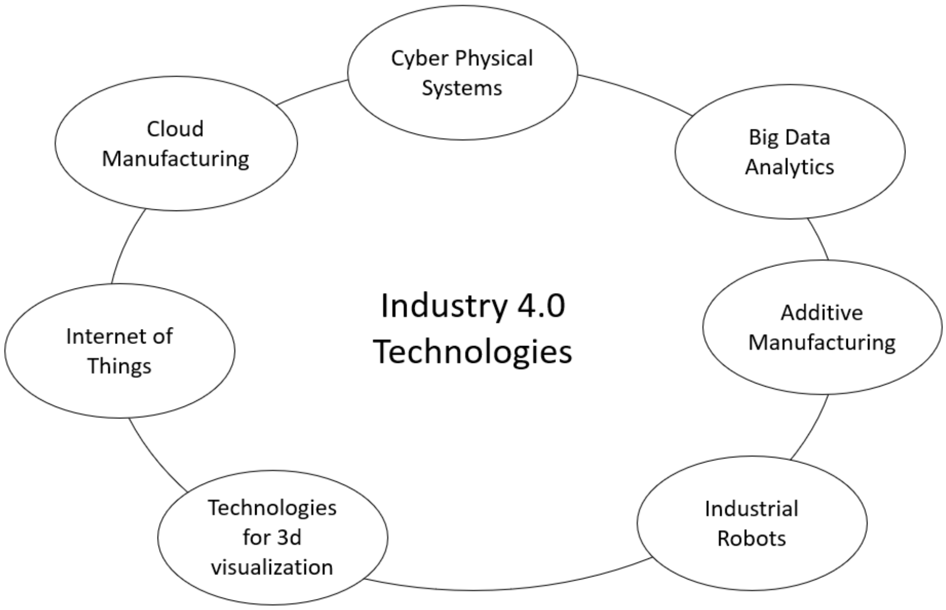

Figure 3 Industry 4.0 technologies

Internet of things

The Internet of Things (IoT) represents networks of electricity, software, sensors, network connectivity, and embedded 'things' or physical objects (Kang et al., 2016). IoT builds on various technologies:

- Sensors, RFID and barcode: these are technologies that allow for the control and the sensing of technologies. Sensors allow for detecting events or changes in their environment and sending the information to other technologies in a network. Radio-frequency identification (RFID) enables automatic identification and data capturing without any human interactions. RFID technology uses electromagnetic fields to automatically identify and track tags attached to objects and store electronic information. There are five types of RFID: The class 1 tags are only passive tags with a read/write memory. Some security-related functionalities are added to class 2 tags. Semi-passive tags (class 3) are powered by a battery and may include sensors.

Active tags (class 4) are also battery-powered and can communicate with similar tags. Lastly, class 5 tags can activate other tags and are directly connected to back-end networks (López, Ranasinghe, Patkai, & McFarlane, 2011). Barcode is also a technology suitable that is an optical and machine-readable data presentation by varying the widths and spacings of parallel lines (Ratnasingham & Hebert, 2007).

- Wireless network: it is a way to send data or information between two or more points which are not connected physically by any conductors, such as cables or wires (C. Liu & Zhong, 2017). In IoT, a wireless connection creates the backbone for a network within the organization with the following protocols: IEEE802.11x, Bluetooth (IEEE802.15.1 and .2), IEEE802.15.4, ZigBee, and IEEE1451.5 that allow all the manufacturing objects and machinery to be identified, connected, and reacted (Kagermann et al., 2013).
- Middleware technology: it is a service-oriented software layer that allows the integration and communication among various devices, including I40 technologies, sensors, actuators or RFID tags.
- Interface layer: it serves to display information and allows interaction M2M, namely man-to-man, man-to-machine, and machine-to-machine.

As a result, IoT develops an IT infrastructure where technologies and physical products are equipped with sensors (Ben-Daya et al., 2017; Kang et al., 2016) that make objects sensed or controlled technologies (Kang et al., 2016). Moreover, IoT allows for collecting and communicating real-time data between technologies and humans (de Sousa Jabbour, Jabbour, Foropon, et al., 2018). IoT also allows organizations to acquire various data from the technologies that enable big data analytics and realise CPS and cloud manufacturing (Kang et al., 2016).

Big Data Analytics

In an I40 context, a massive set of data are acquired from I40 technologies and stored on a large database in-house or in-cloud. These data are named “Big Data” and have the 5 Vs characteristics (Fosso Wamba, Akter, Edwards, Chopin, & Gnanzou, 2015):

- Volume: a large volume of data that either consume huge storage or consist of a large number of records.
- Variety: data generated from a greater variety of sources and formats and contain multidimensional data fields.
- Velocity: frequency of data generation and/or frequency of data delivery.

- Veracity: inherent unpredictability of some data requires analysis of big data to gain reliable prediction.
- Value: the extent to which big data generates economically worthy insights and benefits through extraction and transformation.

Big data analysis is challenging because it cannot be conducted using traditional data process methods due to its complexity. However, successful big data analysis can reveal patterns, trends, and associations, especially relating to human behaviour and interactions (Mikalef, Pappas, Krogstie, & Giannakos, 2018). Big Data analytics tools also represent a viable and holistic approach to manage, process, and analyse these big data to create actionable insights for sustained value delivery, measuring performance, and establishing competitive advantages (Fosso Wamba et al., 2015).

Moreover, the analysis of big data from I40 technologies permit predictive analytics over technology and extract value by technical, special systems and methodologies, such as analysis, capture, data curation, search, sharing, storage, transfer, visualization, and information privacy (Shahbaz et al., 2012). Also, big data analytics is a suitable solution for various manufacturing problems. Lee at al. (2013) explain that sensors conjointly with Big data may facilitate data collection for monitoring the status of manufacturing plants. In this way, it is possible to change or fix technology components parts in advance, avoiding machine degradation, component wear, and lack of lubrification.

Cloud Manufacturing

Cloud Manufacturing is a virtual network in which supply-chain actors share manufacturing capabilities on-demand through the Internet. The manufacturing resources available become services that are displayed on a platform (Zhong, Xu, Klotz, & Newman, 2017). Cloud manufacturing aims to share resources and enhance manufacturing service providers delivering cost reduction, scalability, and flexibility (de Sousa Jabbour, Jabbour, Foropon, et al., 2018). The manufacturing resources are interconnected, and they constitute a shared pool of services displayed on a platform (Siderska & Jadaan, 2018). Cloud manufacturing is often coupled with tracking systems or manufacturing enterprise systems (MES). Tracking systems represents a set of integrated systems that use mobile devices, barcode scanners, QR code scanners and image recognition to trace work and material flow on the assembly line. The system can be either automatic or manually operated by workers using manual barcode scanners. Manufacturing enterprise systems refers to a system integrating inbound,

production and logistic units. Also, it is integrated with the corporate ERP for collecting customer orders, and with the traceability system and augmented reality application to provide statistics.
The distribution of cloud manufacturing follows three types of service: Software-as-a-Service, Platform-as-a-service and Infrastructure-as-a-service (L. Zhang et al., 2014).
Software-as-a-Service (Saas). In the SaaS model, the provider offers a software on-demand that the customers use. Software's license is purchased and used on-demand. SaaS applications support the customization of the application. Each customer may have its settings for the configuration options.
Platform-as-a-service (PaaS). A PaaS platform allows developers to write an application that runs on the cloud. It has a highly scalable multi-tier architecture. The difference in PaaS from SaaS is that SaaS only host completed cloud application while PaaS provides a development platform for both finished and in-progress cloud application. PaaS offers an environment where coders can develop and deploy applications and do not need to know how much memory and how many processors their application will be using. The provider provides the networks, servers, storage, and other services that are required to host the consumer's application.
Infrastructure-as-a-service (IaaS). It offers a service to get a virtual server in a few minutes and pay only for the resource that the customer uses. In the IaaS model, the consumer can directly use infrastructure components, including server, storage, CPU and memory. Customers can self-provision this infrastructure using a Web-based graphical user interface that serves as an IT operations management console for the overall environment.

The cloud manufacturing system is composed of four layers (Xu, 2012). The Manufacturing Resource layer encompasses the required resources during the product development life cycle: manufacturing physical resources and manufacturing capabilities. Manufacturing physical resources include elements, such as hardware or software, and materials. The manufacturing capabilities are intangible recourses representing the capability, skill and competences of an organization to undertake a task. The virtual service layer aims to identify manufacturing resources, virtualise them, and make them cloud manufacturing services. Using IoT technologies, such as RFID, barcode and sensors, manufacturer organizations can give each of their physical assets a digital identity to employ them as-a-service by the layer. The global service layer relies on a suite of cloud deployment technologies, in which it is possible to use as-a-service different cloud features for manufacturing enterprises. Two types of global service layer exist: complete service mode, where the global service layer takes full responsibility for the entire cloud operational activities, and partial service mode refers to activities partially hand over by the cloud manufacturing service. The application layer is an interface between the user and the manufacturing cloud resources (Xu, 2012).

Additive Manufacturing

Additive manufacturing is an “umbrella term” enclosing several technologies that produce goods by adding material rather than mechanically removing material from a solid block (Bassi, 2017). In this group, 3D printings are the most common and famous technologies. Computer-aided design (CAD) package creates 3D printable models that result in relatively fewer errors than other methods. Errors in 3D printable models can be identified and corrected before printing (Huang, Liu, Mokasdar, & Hou, 2013). 3D printings produce the good through light, ultrasonic vibration, laser, and electron beam (Kang et al., 2016). These technologies may use a wide range of various metals, plastics and composite materials (Braccini & Margherita, 2019). These technologies allow for the rapid prototyping of products, consisting of the quick fabrication of a physical object’s scale model (MacDonald et al., 2014). Moreover, thanks to the recent improvements, these technologies allow for a real production of high-quality components and personalized products in small batches at reasonable costs (Bassi, 2017). Some studies also revealed that additive manufacturing, compared to the existing manufacturing methods, has advantages: material efficiency, resource efficiency, flexibility, production flexibility, and limitations related to the size (Huang et al., 2013; Wong & Hernandez, 2012).

Technologies for 3d visualization

The group includes the following technologies: virtual reality, augmented reality, hologram. These technologies allow for the set-up of a simulated, immersive, and interactive virtual environment (Göttig, Newton, & Kaufmann, 2004). Virtual reality and augmented reality share computer-generated visual scenes and a wide variety of interactive components. The primary difference between these two technologies lies in their use: augmented reality supplements the world, while virtual reality tends to substitute the real world with virtual objects completely, that is, a computer developed world (Zaghloul, 2020). The application of augmented reality requires proper hardware and software. The hardware necessary is display equipment, including Head-Mounted Display (HMD), handheld devices or projectors, user tracking equipment, and haptic and force feedback equipment. The software is Computer Vision (CV)-based algorithm of monitoring and registration, and other software that supports natural feature tracking and Parallel Tracking and Mapping (Kang et al., 2016).

In contrast, holograms represent manipulated objects to achieve the desired outcome. Thus, it is possible to view an image long after the item’s withdrawal through holography (Zaghloul, 2020). In an I40 context, these technologies facilitate the design of products, operation planning, factory layout planning, system maintenance without using real materials (Kang et al., 2016). Although these technologies are in an early stage, Zawadzki et al. explain how the synergy between virtual reality and knowledge-based engineering system allows the creation of a non-real prototype, with which many tests and studies are conducted without the expenditure of materials and time and providing a reduction of 80% in routine tasks (Zawadzki & Zywicki, 2016).

Industrial Robots

Industrial robots are machines capable of automatically carrying out complex production and logistics activities; robots are programmed by software, allowing for their management (Mourtzis, Fotia, Boli, & Vlachou, 2019). In an I40 context, robots are often adopted along the production line and in the logistics unit. Concerning robots for the logistics unit, I found applications that automated warehouse management by sensors, but the most common application is the automated forklift. An Automated Forklift is a self-driving computer-controlled forklift that moves and transports goods independently without human intervention. The forklift is designed to provide both horizontal and vertical movement of the load. They can also be configured to stack loads in racks. The automated forklift trucks are increasingly becoming a must in manufacturing premises and warehouses where operations are highly standardized, repetitive, and easily accomplished without human intervention. The automated forklift is programmed to move freely in the logistic unit and it embedded sensors that allow the machine to stop when it encounters an object or a person (Reaidy, Gunasekaran, & Spalanzani, 2015).

Concerning robots for the production line, I found autonomous and collaborative robots. Autonomous robots are designed to work without human interaction (Bzhwen A. Kadir & Broberg, 2020). They conduct activities in place of employees and located in cages because they can harm people because they performed repetitive and hard tasks rapidly (B. A. Kadir, Broberg, & Souza Da Conceição, 2018). This is the case of mechanical arms that can pick and handle heavy materials. They can conduct operations on them, such as modelling, welding, gripping or cutting (Mohd, Mohd, Nor, & Muhamad, 2016). Collaborative robots (or Cobots) are robots designed to work with people. They can handle, move and assembly small objects. Cobots are not dangerous for people because they carry on soft operations. For this reason, they do not require a cage and can be installed along the production line. (B. A. Kadir et al., 2018).

Cyber-physical systems

The plethora of extant I40 technologies allows organizations to customize their I40 adoption by choosing the technologies more suitable for their needs. The integration of the I40 technologies down the production process allows for deploying the generic concept of cyber-physical systems (Kagermann et al., 2013).

Cyber-physical systems (CPS) describe IT technological basis in combination with the physical world, namely the connection of information technology with mechanical and electronic elements (Drath & Horch, 2014). Based on collaborating computational entities, these systems are in a steady intensive connection with the surrounding physical world and its ongoing processes (Monostori, 2014). Cybernetic systems are a summation of logic and sensor unit, while physical systems summarise actuator units. Through the ability to interact and expand capabilities of the physical world using computing power, communication technologies and control mechanisms, CPS allow feedback loops, improving production processes and optimum support of people in their decision-making processes (Blunck & Werthmann, 2017).

With the combination of cyber and physical systems, data are traced, and technologies communicate with people (Kagermann et al., 2013). These open and integrated systems collect data in various physical world situations; they interpret them and make them available (Hozdić, 2015). In a manufacturing context, cyber-physical systems are built on embedded sensors, processors, software, and connectivity in products, coupled with a product cloud in which product data is stored and analysed. These data help to improve product functionality and performance (Stock & Seliger, 2016). These systems can react via actuator systems to processes within the physical world, and therefore they can influence the behaviour of equipment, things and services (Blunck & Werthmann, 2017).

Thus, organizations can exploit data retrieved by the cyber-physical systems to address mechanical issues along the production line. The modern manufacturing industries perform process enhancement and optimization after problems happen or by planned maintenance. Organisations collect information related to the issue when a problem occurs. That is analysed to find out the cause of the problem or organizations plan maintenance to keep working the machine (C. K. M. Lee, Yeung, & Cheng, 2015). However, in this way, it is not possible to predict accidental problems. In contrast, cyber-physical systems control the machinery and collect collecting real-time data along the assembly line. Thus, they can prevent the emerging of these issues that are promptly addressed by autonomous machines and without human interaction (J. Lee et al., 2015).

Therefore, by employing the work system theory, which considers a production process as a work system. This work system is composed of the technical system – the technology – and the social system – workers (Alter, 2002, 2013; Bostrom & Heinen, 1977). The cyber-physical systems can be conceptualized as a complex socio-technical system that intervenes in the I40 production process.

The technical system embraces all the integrated I40 technologies, and the social systems include all the human actors that work along the production line.

2.2 The concept of sustainability

The word *sustainability* has its root from the Latin word *sustenere* that means to hold up or keep elevated.

Sustainability has historically been used as a synonym of its corollary sustainable development, which chiefly refers to natural resource sustenance (Dixon & Fallon, 1989).

The concept already appeared in 1713 when Carlowitz edited the first book on forest sciences. He claimed that the timber would be" "as important as our daily bread", and this requires to be "used with caution in a way, that there is a balance between timber growth and lumbering".This strategy allows for a forever, continuous, perpetual use of the forest. "For this reason, the economy needs to be set in a way that allows people to avoid suffering scarcity, and where it is lumbered, we should strive for young growth at its place" (Carlowitz, 1713).

In the XX century, the book The Limit of Growth by Meadows et al. rekindled this debate focusing on industrial growth (1972). Although industrial revolutions produce several benefits for humanity, the increasing usage of technologies has accelerated the production of goods and increased natural resources exploitation (Habakkuk & Postan, 1966). These adverse effects would result in serious, potentially irreparable harm to humans. Thus, the discussion was initially framed in terms of famine and over-population. Then it has turned to the function of ecosystems and the consumption of natural resources (Marshall & Toffel, 2005).

Nations acknowledged the importance of sustainable development in 1972 at the United Nations Conference on the Human Environment in Stockholm. In Stockholm, 113 countries started debating the global human impact on the environment. This conference was an attempt at forging a fundamental common outlook on how to address the challenge of preserving and enhancing the social environment. As a result, the Stockholm Declaration presented 26 principles, considered environmental policy goals and objectives (Kidd, 1992).

Another fundamental stage was the Brundtland Commission in 1987 that drafted the Brundtland report. The document aimed at popularizing and defining the term "Sustainable Development": "meets the needs of the present without compromising the ability of future generations to meet their own needs"(WCED, 1987 p.43).

After that, the importance of the concept of sustainability increased dramatically. Even though some have criticized this definition as difficult or impossible to operationalize and implement, policymakers, practitioners, and scholars continue to debate sustainable development, creating solutions and frameworks to assess it (Marshall & Toffel, 2005).

Many international conferences came in succession to the Brundtland Commission, such as Rio 1992, Johannesburg 2002, and Rio 2012. In Rio 2012, the international commission reached an agreement on the concept of sustainability. They coined the "Sustainable development goals" as a synthesis of the sustainability concept that is 17 goals to reach for the creation of a more sustainable world. Figure 4 graphically summarizes the sustainable development goals. These goals acknowledged the inclusion of social aspects in the concept of sustainability. Thus, the current concept of sustainability includes both environmental and social issues.

Figure 4 Sustainable Development Goals

In the organizational context, sustainability appeared with the frameworks of eco-efficiency and sustainable innovation – or eco-innovation or environmental innovation (Boons, Montalvo, Quist, & Wagner, 2013; Yu, Chen, Zhu, & Hu, 2013).

Eco-efficiency means doing more with less or producing economic outputs with minimal natural resources and environmental degradation (Yu et al., 2013). Sustainable innovation refers to an innovation that improves environmental performance for organisations (Boons et al., 2013).

Both frameworks share the same idea of sustainability, which aims to address environmental issues and support economic growth. Although these frameworks are used for a decade (Boons et al., 2013), they do not provide a comprehensive sustainability assessment.

Since companies can create multiple challenges for society, with social, environmental, and economic consequences (Porter & Kramer, 2019), these frameworks allow assessing sustainability exploring how novel technologies mitigated the organisational environmental impact, but they do not cover social aspects.

For example, human rights abuses, child labour, and irresponsible investment need to be incorporated as part of sustainable development (Ghadimi et al., 2019). However, due to the lack of available tools for social indicators and the subjectivity nature of those indexes, social aspects have received less attention than the environmental and economic aspects (Kamble et al., 2018). The triple bottom line framework by Elkington, on the other hand, presents a holistic framework that wants to embrace also the social aspects of sustainability together with the economic and environmental bottom line.

2.2.1 The triple bottom line

The triple bottom line is a multi-dimensional framework for addressing organizational sustainability (Elkington, 1997). The term was coined in 1994 by John Elkington that introduced the triple bottom line framework in detail in his book *Cannibals with Forks* (Elkington, 1997). The triple bottom line objective was to counter the narrower focus on the term eco-efficiency, which focused on the money to be made or saved in the more efficient use of natural resources and pollution reduction and measures sustainability by the financial and environmental dimensions of organizational performance.

The triple bottom line approach both widened the financial dimension to consider a range of economic externalities and introduced the social dimension —which at the time was much less acceptable to business leaders, particularly in the United States (Hartmann, 2020).

The triple bottom line has considered a practical framework to assess sustainability (Goel, 2010; Rogers & Hudson, 2011). The triple bottom line framework is composed of three dimensions: the economic, environmental, and social dimensions. Figure 5 graphically represents the framework of the triple bottom line.

The economic dimension represents the company's economic bottom line and monetary flow. It refers to the impact of the organization's business practices on the economic system (Elkington, 1997). It pertains to the economy's capability as one of the subsystems of sustainability to survive and evolve into the future to support future generations (Spangenberg, 2005).

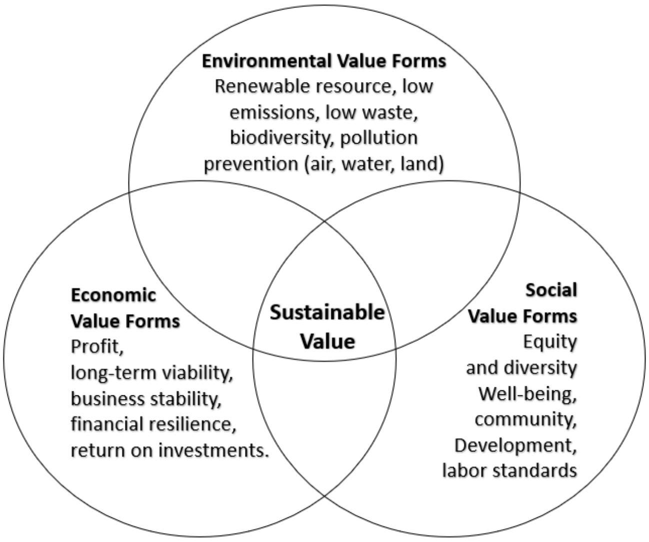

Figure 5 The framework of the triple bottom line retrieved from Savaget, Geissdoerfer, Kharrazi, & Evans, 2019

This dimension includes aspects to the organizational idea to generate economic value in order to guarantee the possibility of delivering products and services to the market with a mark-up between revenues and costs, either through increased added value in the production or through cost reduction during the production process (Kiel et al., 2017). This dimension focuses on monetary values but includes both financial and non-financial indicators. Examples of financial measures are sales, profits, return on investment, cash flows, and paid taxes. Examples of non-financial measures are supplier relations, average incomes, and sector revenues (Hartmann, 2020).

The environmental dimension represents the company's interrelation with the impact on the ecological environment. It puts the focus on how the company uses and impacts the natural resources of the planet. Thus, the dimension refers to the organizational idea to create value to alleviate pressure on the environment by rationalizing natural resource usage, efficient energy consumption, renewal energy consumption and reducing emissions and pollution (Hertel & Wiesent, 2013). Examples of indicators in this dimension are carbon dioxide emission, water and energy use, amount of waste generated, biodiversity impact, and recycled material use (Hartmann, 2020).

The social dimension represents the company's interrelation with the social environment and focuses on how it uses and impacts human resources. The dimension refers to the organizational idea to create value to conduct fair business practices to benefit the workforce, community, and society. This dimension broadens the perspective of the organization to cover all stakeholders. It requires the organization to manage long-term survival and simultaneously deal with social issues related to community involvement, employee relations, fair wages, quality of life, social integration in communities, solidarity, equity and justice, and equal education opportunities (Kiel et al. 2017). This dimension includes indicators, such as educational activities, health and safety records, work security measures, community impact, and corruption-avoidance mechanisms (Hartmann, 2020).

The economic, environmental and social dimensions of sustainability are interdependent. Each dimension represents a necessary but not sufficient condition for achieving sustainability: when organizations do not support one of these dimensions, they do not act sustainably (Norman & Macdonald, 2004). To achieve sustainability, organizations need to simultaneously support all three dimensions in their business models (Jayaprakash & Pillai, 2019).

However, the three dimensions are frequently in conflict, as actions to pursuit environmental or social sustainability do not always turn into improved economic sustainability and vice versa (Ozanne et al., 2016). For instance, environmental sustainability could be detrimental to economic sustainability due to the extra investments needed for cleaner production processes. Similarly, in order to create an additional pension fund for workers, organizations can reduce the economic gain, thus reducing the support of the economic dimension. Moreover, measuring all the three dimensions of the triple bottom line is difficult because the individual indicators do not share units of measures (Hartmann, 2020). Although the economic dimension can be measured with economic indicators, environmental and social aspects require different indicators. No-Profit organizations, like the Global Reporting Initiative, proposed some standards to regulate these indicators in the last years. Nonetheless, the exploitation of the triple bottom line remained a problematic path for organizations.

3 Literature Review

A literature review is needed to report the state of the art of the research since the dissertation is framed on two separate research streams (Webster & Watson, 2002). I conducted the literature review during my first year of PhD period from January 2018 to June 2018. Then, I periodically update the results of the review by October 2020. I conducted the review over Scopus, Google Scholar and Web of Science databases. To conduct a more thorough and in-depth literature review, I include in the keyword search synonyms of the two main topics, Industry 4.0 and sustainable value creation (Levy & Ellis, 2006). I used the following keyword search: "industry 4.0" OR "industrial internet" OR "internet of thin*" OR "smart factor*" OR "cyber-physical system*"AND "sustainability" OR "sustainab*" OR "sustainable value creation". Moreover, I found in the results some literature review of Industry 4.0. Thus, I conducted a backward and forward search to embrace further studies which are in line with the purpose of my literature review (Levy & Ellis, 2006). I refined the research, including only articles written in English.

In June 2018, the keyword search revealed 386 studies. By reading the title and abstract, I selected 25 paper. I dropped several I40 studies in the first step since the author discussed I40 applications of different sectors like smart building, agriculture and e-health. Indeed, the authors employed the I40 term referring to the interconnection feature of the initiative making the query wider. Still, I dropped several conceptual papers because they discuss the ideas, applications, and the sustainable value creation of I40 adoption but do not collect primary data or analyse secondary data. I chose ten papers by reading the full text. Then, I reached 18 papers by the backward and forward search. After these steps, I periodically updated the review. In September 2020, when I wrote this paragraph, the literature review reached 51 papers.

To present the literature review results, I follow the recommendation by Webster & Watson, who claims to illustrate the result of the analysis with a concept-centric matrix. A Concept-centric matrix is a favourable way to synthesize the literature by discussing each identified concept and form in the table to communicate major findings and insights (Webster & Watson, 2002). Table 1 summarizes with a concept-centric matrix the findings of the research.

Sustainability Dimensions:	**Attributes**	**Short Description**	**Most Relevant References**
Economic Dimension	Improved production process	I40 promises to improve the production process, delivering higher productivity, higher quality products, and valuable services.	(Fatorachian & Kazemi, 2018; Kagermann et al., 2013; Kiel et al., 2017; Thoben et al., 2017)
	Improved customer satisfaction	I40 applications improve customer satisfaction through the increased personalization capabilities of production processes.	(Braccini & Margherita, 2019; Fatorachian & Kazemi, 2018; Kagermann et al., 2013)
	Increased supply chain efficiency	I40 applications improve the efficiency of supply chain management, thus reducing inventory inaccuracy.	(Ben-Daya et al., 2017; Y. Lee, Kim, Lee, & Moon, 2017; Y. Zhang et al., 2018)
Environmental Dimension	Reduction of natural resource and energy usage	I40 applications reduce natural resource usage and result in energy savings via more precise data granularity vis-à-vis technology.	(Bressanelli, Adrodegari, Perona, & Saccani, 2018; Kagermann et al., 2013; Oláh et al., 2020; Schulze et al., 2018)
	Reduction of CO2 emissions	I40 applications better manage the logistics between the production process and warehouse, thus reducing transport and CO2 emissions and decreasing fuel usage.	(Gabriel & Pessel, 2016; Herrmann, Schmidt, Kurle, Blume, & Thiede, 2014; Liang et al., 2018; Oláh et al., 2020)
Social Dimension	Reduction in the number of work accidents	I40 technologies automate unhealthy and dangerous production phases.	(Braccini & Margherita, 2019; Gregori, Papetti, Pandolfi, Peruzzini, & Germanu, 2018; Kagermann et al., 2013; Yuan, Qin, & Zhao, 2017)
	Improved workforce morale	The workforce enjoys a better work environment more oriented towards workers' needs.	(Kagermann et al., 2013; Y. Lee et al., 2017)
	Increasing safety at work	The deployment of I40 technologies increases safety across the production process.	(Braccini & Margherita, 2019; Kagermann et al., 2013; Kembro, Danielsson, & Smajli, 2017)
	Reduction of repetitive activities	The I40 adoption automates the activities of repetitive workers.	(Bonekamp & Sure, 2015; Gabriel & Pessel, 2016; Kagermann et al., 2013)
	Increasing autonomy for workers	The automation of repetitive activities leaves workers in charge of more creative, innovative that requiring more autonomy.	(Erol et al., 2016; Fettig, Gacic, Koskal, Kuhn, & Stuber, 2018; Shamim et al., 2016)
	Workforce substitution	By automating, I40 technologies reduce the size of the workforce employed in the production process.	(Bonekamp & Sure, 2015; Frey & Osborne, 2017; Kang et al., 2016)
	Reduction of workforce core activity	I40 technologies accomplish core tasks that workers were previously in charge.	(Bonekamp & Sure, 2015; Nurazwa et al., 2019)
	Reduction of competencies, expertise know-how of workers	The automation does not allow workers to train, increase and maintain their expertise in the production process activities.	(Bonekamp & Sure, 2015; Nurazwa et al., 2019)

Table 1 State of the art of sustainable value of I40 technologies

3.1 State of the art of the sustainable value creation of Industry 4.0 technologies

In the existing literature of sustainable value creation of I40, the contributions are mainly attributed to the economic and environmental dimensions of the triple bottom line. Also, these dimensions are supported singularly (Kamble et al., 2018).

Economic Sustainability

I40 adoption supports the economic dimension delivering an improved production process, enhanced customer satisfaction, and an increased supply chain efficiency (Ben-Daya et al., 2017; Fatorachian & Kazemi, 2018; Kagermann et al., 2013; Thoben et al., 2017). I40 adoption helps to improve and automate the production process with advanced technologies that deliver various economic advantages. The increasing automation allows maintaining a constant production process reducing human errors (Gabriel & Pessel, 2016; Kagermann et al., 2013). Thus, I40 adoption leads to a higher production quantity. Moreover, this automation and the increased connectivity throughout manufacturing value chains leads to reduced costs, lead times, and enhanced quality of products (Oesterreich & Teuteberg, 2016). I40 adoption also enables the dynamic and flexible configuration of various business elements, including time, risk, robustness, and price (Kagermann et al., 2013). This can eventually lead to the creation of agile engineering and manufacturing processes, which allow producing only the desired quantity of products at moderated production costs (Fatorachian & Kazemi, 2018). I40 adoption also facilitates the production of the various gamut of products as these novel technologies can directly read CAD projects, and they are more accurate in operations. Data produced by I40 technologies are mined to gather information to improve the product manufacturing life cycles and economic performance (Shahbaz et al., 2012).

I40 perspective enables meeting individual customer requirements by the inclusion of individual customer-specific criteria in the process of production (Kagermann et al., 2013). The adoption of IoT and CPS allows the development of a platform for automation and integration of machinery and devices (Leitao et al., 2016), facilitating the rapid transferring of customer requirements into production processes. I40 technologies also enable a high level of flexibility and permit last-minute changes to the production process (Helo & Hao, 2017). Zawadzki & Zywicki also highlighted how the adoption of additive manufacturing enables the mass customization that allows the production of goods with customizations. These pieces are combined to produce the good and eventually reused. In doing so, I40 organizations enjoy the advantages of creating a personalized offer and the benefits of mass production (Zawadzki & Zywicki, 2016).

In the I40 manufacturing environment, the high level of connectivity integrates the factory floor operations with enterprise-based systems and decision support tools that improve supply chain management efficiency (Fatorachian & Kazemi, 2018). The literature reviews revealed several studies of the logistic units. I40 technologies help increase organisational logistics performance (Ben-Daya, Hassini, and Bahroun, 2017). Some studies showed how inventory management and warehouse management based on IoT applications improve supply chain management efficiency, reducing the inventory inaccuracy and shorter time to markets (Ben-Daya et al., 2017; Cui et al. Moreover, Wang showed how cloud manufacturing integrates the organisational internal value chain, developing a service-oriented system based on the internet that performs machine availability monitoring and process planning.

Environmental Sustainability

Implementing I40 technologies contributes to addressing environmental issues and, therefore, to support the environmental dimension. I40 technologies improved resource usage control thanks to more accurate and granular information on energy and resource usage (Liang, Lu, Li, and Wang 2018; Schulze et al. 2018). By automating the production process, I40 technologies also help decrease the number of damaged products by workers and, eventually, the defected product rate. Thus, Industry 4.0 adoption contributes to minimizing the waste in general and natural resource waste in production processes (Gabriel and Pessel 2016; Herrmann, Schmidt, Kurle, Blume, and Thiede 2014). Moreover, I40 adoption facilitates circular economy practices. Particularly, IoT application supports remanufacturing processes providing tracking of components product and eventually increases the speed to reassemble products (Y. Zhang et al., 2018). Also, the feature of fast prototyping provided by additive manufacturing allows organizations to reduce the time and the number of product prototypes. In this way, the waste of raw materials and energy during the prototype phase has decreased drastically (Brundage, Arinez, Chang, & Xiao, 2015).

Similarly, virtual reality proposes the opportunity to present a virtual prototype without using natural resources and therefore reducing product prototypes (Zawadzki & Zywicki, 2016). Some studies showed that the analysis of big data, retrieved by an I40 application, with a predictive model allows forecasting and reducing energy consumption with the maintenance of technical efficiency within the organization (Liang et al., 2018; Shin et al., 2014). Analogously, a study presented an I40 application that also leads to productivity improvement, energy-saving, and a resulting reduction of CO2 reduction (Thiede, 2018).

Literature also reports that the environmental dimension is conflicting with the economic dimension, as environmentally sustainable products and processes are costly for companies, and customers tend not to be willing to pay more for cleaner products and services (Q. Liu, Li, Zuo, Zhang, & Wang, 2009; Y. Liu & Bai, 2014). Still, the shift of production towards mass customization, that is, the production of goods with customizations, opens several challenges for circular economy practices. Products are difficult to reassemble and use as secondary raw materials (Oláh et al., 2020). Moreover, the increasing automation of Industry 4.0 opens for ecological challenges. Although I40 technologies optimize the production automating a large part of the process, the amount of generated data drastically increases.

Consequently, the energy consumption of manufacturing organization increases by this data interchange (Julian M Müller & Voigt, 2018). Organizations addressed these tensions through an I40 adoption, which allows producing only when there is a demand for these products and with a production process that minimizes the use of resources, materials, energy, and the creations of wastes (Oláh et al., 2020). Also, a modularization strategy is a suitable way to address this tension. This is an architecture that decouples products into subsystems with very little interdependencies in order to achieve economies of scale. It can stem these environmental issues as the standard part of various products can be quickly recycled (Bressanelli et al., 2018).

Social Sustainability

Concerning the literature related to the social dimension, I found conflicting results due to the delivered I40 automation that generates tensions between the social and economic dimensions of the triple bottom line. Few studies report the qualitative benefits of I40 adoption. I40 technologies provide potential benefits for labour, delivering safer and healthier workplaces (Bednar & Welch, 2020; Kagermann et al., 2013). By automating harmful activities, I40 technologies increase safety at work (Gabriel & Pessel, 2016). Automation takes on repetitive and dangerous tasks from the workforce, reducing the risk of work accidents and increasing workforce morale (Y. Lee et al., 2017; Schulze et al., 2018). I40 may improve workforce conditions by automating hard-muscular activities leaving for the workforce control tasks and problem-solving to manage unexpected technology issues (Gabriel & Pessel, 2016; Kagermann et al., 2013). The replacement of workers with machines for repetitive tasks leaves workers to more creative, innovative and communicative activities, increasing workers and teams autonomy (Erol et al., 2016; Shamim et al., 2016). Thus, workers can contribute to the production process optimization and develop new ideas for improved products and services. In line with this evidence, Gregori et al. show how an IoT infrastructure can acquire human-related data of a production site to improve workers' wellbeing and overall productivity.

While further studies describe the negative consequences of automation from the social sustainability perspective that conflicts with economic sustainability, these studies of I40 technologies use a “technocentric” approach that considers the I40 automation as the main enabler to create organizational value (Kang et al., 2016). Under this perspective, the workforce can be replaced by technologies to seek productivity and profitability, and automation contributes to job disruption (Kang et al., 2016; Wright & Schultz, 2018). Manufacturing organizations have already experienced automation with a consequent job disruption for blue-collar workers since manufacturing processes are well suited for the automation being composed of repetitive and well-defined activities (Frey & Osborne, 2017; Wright & Schultz, 2018). Thus, I40 deployment advances this job disruption automating the entire production process (Kang et al., 2016), including also decision-making activities, consequently challenging also white collars workers (Bonekamp & Sure, 2015; Kang et al., 2016; Nurazwa et al., 2019).

Also, I40 technologies may degrade competencies, expertise and know-how of blue and white-collar jobs because I40 automates operational and decision-making activities (Bonekamp & Sure, 2015; Nurazwa et al., 2019). Also, I40 technologies contribute to the impoverishment of the labour force as automated cyber-physical systems conduct decision-making activities previously performed by human workers, and this makes the role of the workforce even more marginal within an organization (Liao, Deschamps, Loures, and Ramos 2017; Nurazwa, Seman, and Shamsuddin 2019). Thus, reducing the workforce core activities implies a decrease in workers (Bonekamp & Sure, 2015; Nurazwa et al., 2019). Thus, the adoption of I40 technologies decreases human resources role by de-skilling and reducing the number of low and high-skilled workers as they are replaced by machines (Bonekamp and Sure 2015; Kang et al. 2016; Liao et al. 2017; Nurazwa et al. 2019). Therefore, this changing landscape claims that lifetime employment and career security are no longer the norms in a contemporary manufacturing environment (Chin et al., 2019; Chin & Liu, 2015).

3.2 Gaps in the sustainable value creation of Industry 4.0

As a result of the literature review, I found three main gaps related to the sustainable value creation of I40 adoption, which I summarized in Table 2.

Research gap	Motivation
Lack of studies of the sustainable value that I40 adoption deliver on the three dimensions of the triple bottom line simultaneously	Studies are focused on addressing one dimension with these technologies and not the entire triple bottom line. I40 adoption mainly supports the economic and environmental dimensions. The social dimension is barely investigated. (Ghadimi et al., 2019; Kamble, Gunasekaran, & Gawankar, 2018).
Lack of pieces of evidence of I40 enablers to support the three dimensions of the triple bottom line simultaneously	The automation, the primary I40 enabler, supports one dimension of the triple bottom line singularly but missing to address the triple bottom line simultaneously (Fatorachian & Kazemi, 2018; Kamble et al., 2018).
Lack of pieces of evidence of I40 adoption addresses tensions between economic and social sustainability	I40 application allows organizations to automate even more the production process at the expense of workers (Bonekamp & Sure, 2015; Wright & Schultz, 2018).

Table 2 Research Gaps in the sustainable value creation of Industry 4.0

Firstly, there is a lack of studies showing the sustainable value that I40 adoption delivers on the three dimensions of the triple bottom line simultaneously. Indeed, studies aimed at addressing one dimension with these technologies, mainly the economic and the environmental dimensions. While the social dimension is barley investigated (Ghadimi et al., 2019; Kamble, Gunasekaran, & Gawankar, 2018). Also, triple bottom line achievement failure through I40 technologies relies on the lack of proper organizational actions to implement Industry 4.0 (Sony & Naik, 2019a, 2019b). I40 implementation is a complex process that consists of end-to-end digital integration of technologies and a well-prepared workforce to manage these technologies (Kagermann et al., 2013), and this integration of I40 technologies is challenging for organizations as there are no best practices to follow. Also, there is a scarcity of experts to lead the I40 projects (Sony & Naik, 2019b). Moreover, the workforce is not prepared to manage these technologies due to a lack of proper competences and skills, which causes a strong workforce resistance against I40 adoption (de Sousa Jabbour, Jabbour, Foropon, et al., 2018; Liao et al., 2017; Julian M. Müller, 2019). And it may encourage organizations to replace experienced workers with a more specialised workforce.

Secondly, the literature reports the automation as an I40 enabler that allows supporting one dimension singularly but missing to address the triple bottom line. Under the technocentric perspective, the I40 automation is feasible to achieve value on the economic and environmental dimension but barely for the social dimension (Ghadimi et al., 2019; Kang et al., 2016). Thus, the technocentric perspective of I40 adoption is not adequate to simultaneously supports organizational sustainability (Kang et al., 2016). Therefore, there is a lack of studies regarding a holistic position in the literature that shows how I40 adoption and its enablers support organizational sustainability.

Thirdly, achieving the triple bottom line is challenging for organizations because the triple bottom line dimensions are built in a conflictive way that impedes to reach simultaneously economic success, ecological balance, and social justice. The central two tensions are between the economic and environmental dimensions and the social and economic dimensions. Although the tension between the economic and environmental dimension is highlighted in literature and addressed (Julian Müller & Voigt, 2018; Oláh et al., 2020), the tension between social and social dimensions deserves further investigation. Similar to the previous technological advances, this innovation allows organizations to automate even more the production process at the expense of workers. Therefore, organizations may overlook this tension because reducing workers implies decreasing staff costs, which is a financial benefit. Hence, a study that explores how organizations address this tension is pivotal to reach the fulfilment of the triple bottom line by I40 adoption.

4 Research design

In this section, I present the philosophical foundations of my research. I illustrate the multiple case study approach clarifying the case selection, the data collection and data analysis. I conclude by debating how I assure the validity of my findings.

4.1 Philosophical foundations

The philosophical assumption of the researchers has implications for the research design, particularly for qualitative research (Duberley, Johnson, & Cassell, 2012). A research design that is not carefully planned can produce flawed knowledge. Thus, it is crucial to declare philosophical assumptions before presenting the research design (Zalan & Lewis, 2004). The philosophical assumption refers to the views of "what is real, what can be known and how facts can be faithfully rendered" (Miles & Huberman, 1994). I address these questions by discussing the ontological, epistemological, and methodological foundations of the research (Guba & Lincoln, 1994).

Ontology refers to how we view the existence ("the being") of empirical phenomena (Guba & Lincoln, 1994), whether they are created and reproduced without human interference or existing as social constructions (Orlikowski & Baroudi, 1991). Epistemology refers to how we can acquire and generate certain knowledge (Guba & Lincoln, 1994), namely, how researchers can design and conduct our research studies to make valid claims (Orlikowski & Baroudi, 1991).

In terms of ontology, I consider the "reality" as a product of individual consciousness rather than external to the individual. The reality is socially constructed; namely, the interaction among people constructs reality. From the epistemological point of view, I consider knowledge subjective, based on the experience and insights of the individuals studied and dependent on values, rather than objective and independent of values. Hence, the reality is seen by multiple people, and these multiple people interpret the events differently, leaving multiple perspectives of a phenomenon. Thus, knowledge concerns how people make sense and meaning of a phenomenon. Therefore, to acquire knowledge of a phenomenon, the investigation required to use a research method that aims to embrace different points of view of different people, which are familiar with the phenomenon. These assumptions led me to investigate the sustainable value creation of I40 through the individual experiences and perceptions of managers and employees.

Hence, the paradigm that represents my philosophical foundations is interpretivism. The interpretive paradigm is concerned with understanding the nature of the social world at the level of subjective experience (Burrell & Morgan, 1979). The interpretive paradigm considers the social world as an emergent social process that is generated by the individuals concerned (Burrell & Morgan, 1979). The interpretative researcher believes that reality and the individual who observes it are inseparable. This is because a person's views of the world are inextricably linked to their life experiences. It looks for an explanation within the realm of individual consciousness and subjectivity, in the frame of reference of the participant as opposed to the observer of action (Burrell & Morgan, 1979).

The interpretive nature of my study becomes particularly evident when I investigated the research sub-questions collecting data interviewing different key informants related to I40 adoption, namely, the management and workers that acted as the steering committee of I40 adoption. Historically, these two groups of actors have distinct voices related to several topics (Sawyer & Jarrahi, 2014), such as with regard to the consequences of technology automation. This variation implies that I understand the nature of the phenomena at a level of the subjective experience of the participants.

Therefore, this position calls for a contextualized and reflexive approach (Charmaz K., 2006), implying the researchers select and clearly describe the context of the study and explore how, when, and to what extent the studied experience is embedded in a certain context. Researchers take a reflexive stance toward the research process and products and consider how their theories evolve, which includes reflecting on my earlier point that both researchers and research participants interpret meanings and actions (Charmaz K., 2006). Then, researchers interpret the phenomenon against the contexts by analysing data, theory, and the researcher's view. This process-orientation (Langley, 1999) is traditionally associated with qualitative methods, which allows for the usage of various sources of data that can be triangulated and analysed (Denzin, 2006).

4.2 The multiple case study approach

Given the nature of the research and limited body of knowledge of the sustainable value creation of I40 adoption, I consider the exploratory case study approach is the most suitable methodology for the empirical investigation (Yin, 2018). A case study is adequate to study the circumstances (the context) under which some social phenomenon (the "case") occurs, and there is a need for an in-depth inquiry (Yin, 2018). The exploratory case study is appropriate when investigating a poorly researched phenomenon and where data required for formulating hypotheses have not yet been obtained (Eisenhardt, 1989). Exploratory case studies typically address what, how and why questions (Yin, 2018) concerning the dynamics present within a particularly contextual setting to develop initial understandings (Eisenhardt, 1989; Yin, 2018). Thus, a case study allows a deep understating of the phenomenon employing various qualitative and quantitative data, which, through their triangulation, allows depicting an in-depth representation of the phenomenon.

To answer the research questions, I conducted a multiple case study approach. This approach is valuable when "research and theory are at early, formative stages" (Benbasat, Goldstein, & Mead, 1987, pg. 369). A multiple-case study investigates the same phenomenon within several contexts and is suitable for generating more robust theory and to prepare for theory-testing studies (Eisenhardt, 1989; Eisenhardt & Graebner, 2007; Yin, 2018). Firstly, the multiple case study approach allows me to explore each case study in-depth. Then, it allows for comparisons of the findings across the case studies. The ultimate goal of a multiple case study is to clarify whether findings are idiosyncratic to a single case or applied in several cases. Thus, the multiple case study allows establishing patterns of relationships between constructs within and across cases with their underlying logical arguments. For these reasons, Eisenhardt & Graebner argued that the multiple case study approach is more advisable to the single case study in terms of generalization. The method consists of selecting multiple cases, triangulating data during data collection, and analysing the data both within cases and across cases, where data are investigated in many divergent ways (Eisenhardt, 1989; Yin, 2018).
A debated point of the multiple case study is the generalizability of the results (Mills, Durepos, & Wiebe, 2009). The multiple case study does not claim statistical generalization because the cases are not "sampling units" and are too few in numbers as an adequate sample to represent a larger population (Yin, 2018). Instead, the study aims to provide an analytic generalization of the phenomenon, which consists of assuring the transferability of findings from a multiple case study, based on a theoretical analysis of the factors producing outcomes and the effect of context. Also, analytic generalization allows for the development of theoretical propositions that can be statistically tested in future studies (Yin, 2018).

4.3 Case Selection

Since the multiple case study goal is to replicate findings across case organizations, the cases must be carefully selected for the researcher to predict similar or contrasting results (Baxter & Jack, 2008). The case selection followed Yin's recommendation of the replication logic, referring to the choice of cases that predict similar outcomes (literal replication) or predict contrasting results but for anticipatable reasons (theoretical replication) (Yin, 2018).

In this study, I selected five cases according to five criteria:

1. The case units are manufacturing organizations.

2. All case units operate in a similar context, that is, the Italian context, which is the second larger manufactures in Europe[2].
3. The case units adopted different I40 technologies.
4. The case units operate in different industries in manufacturing.
5. The organizations provided me access to a considerable amount of data related to I40 adoption.

The first and second inclusion criteria fulfil literal replication. Being all the cases of Italian manufacturing organizations, I can expect that the cases have similar results of sustainable value creation, which are led to by adopting I40 technologies on the production process. Also, since the organizations operate in an Italian context, they share similar environmental context characteristics. More specifically, they are facing competitors from developed countries that are adopting I40 technologies to increase their productions which exploit similar national funds. These competitors are producing low-quality goods and have a lower personnel cost and taxation level than the Italian organizations. These factors allow the organizations of developing countries to sell products at a lower price and increase their market share. Therefore, the organizations of the unit of analysis decided to adopt I40 technologies to improve the quality of products and their customization in order to fulfil customer's need better. Thus, they want to maintain their market share by selling higher-quality products than their competitors at a premium price. Also, European regulation imposes manufacturing organizations to reduce environmental impact, and I40 technologies foster this production process improvement. Still, they have a common trait, the employment of national funds to improve the production process by adopting I40 technologies.

The third and fourth criteria fulfil theoretical replication. All the cases are manufactures producing different types of goods. This dissimilarity allows predicting a priori a variation of the sustainable value of I40 adoption as I40 technologies promise full loop automation to all kinds of productions, but not just mass production. Moreover, I included organizations adopting different I40 technologies that generate a distinct sustainable value. Still, including various I40 technologies is required to investigate the I40 initiative that has as the building block a plethora of leading-edge technologies for manufacturing organizations (Fatorachian & Kazemi, 2018; Kagermann et al., 2013). Thus, this inclusion criterion also increases the reliability of the study, including eight I40 technologies investigated.

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[2] Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E): https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=sbs_na_ind_r2&lang=en, retrieved: 20/10/2020

The last inclusion criterion reflects the choice to include only cases that can be deeply investigated, which is a prerequisite for an in-depth exploratory multiple case study (Buchanan, Boddy, & Mccalman, 2013; Yin, 2018). The criterion is assured when the organization allowed me to visit the plant and to interview both the steering committee of the I40 adoption and workers involved in the I40 adoption that is the two groups of key informants for my research.

I consider the following cases (Yin 2018) because they allow me to explore how the management of I40 technologies currently and potentially address sustainability issues and how they address the tension between the social and economic dimension. Table 3 summarizes the contextual information of the organizations, which are extensively described below.

Case	Organizational Size	Location	Reference Market	Industry	Adopted Industry 4.0 technologies
A	Small Medium	Italy – Lazio region	International	Ceramics	• Mechanical Arms • Internet of Things • Automatic forklifts
B	Small Medium	Italy – Tuscany region	International	Kitchen furniture	• Mechanical Arms • Digitally programmable sewing machine, • Automated warehouse • Manufacturing enterprise system (MES).
C	Small Medium	Italy – Marche region	International	Leather	• Traceability systems.
D	Small Medium	Italy – Lazio region	Italy	Orthopaedic prostheses	• Mechanical Arm • Traceability systems
E	Large	Italy – Lazio region	International	Electrical Switches	• Traceability systems • Semi-automatic conveyor belt

Case	Organizational Size	Location	Reference Market	Industry	Adopted Industry 4.0 technologies
					with smart sensors • Robotics • Augmented reality application • Data analytics • manufacturing enterprise systems (MES).

Table 3 Contextual Information of the organizations

Case A (QUEMIC a fantasy name): This is a manufacturer of sanitary ceramics that implemented mechanical arms and automated forklifts in a fully automated and integrated process in which workers perform supervisory roles and fine-tune IoT-controlled machinery. The company also maintained the traditional labour-intensive process in place. QUEMIC is very attentive to the negative environmental impacts of the organization as the production process is resource and energy-consuming. QUEMIC employs about 220 employees.

Case B (ALESWOOD a fantasy name): This is a kitchen furniture manufacturer that automated some operations of the transformation process. Workers supervise IoT-controlled machinery, and a tracking system on the assembly line supports workers in the assembly task. ALESWOOD employs sustainable wood and for its product and is attentive to the work conditions of human resources. ALESWOOD employs about 200 employees.

Case C (STYLORIUM a fantasy name): This is a leather manufacturer that integrated digital technologies to improve the traceability of materials and operations on the assembly line. STYLORIUM adopted a tracking system that assists workers and provides visibility in terms of the time and costs needed to complete lots and respect performance targets. STYLORIUM leverages worker competencies for high-quality products. STYLORIUM trains young workers with an academy, which won an innovation award. STYLORIUM employs about 90 employees.

Case D (HYVUM a fantasy name): This is a manufacturing industry that produces orthopedic prostheses that adopted autonomous mechanical arms in the manufacturing process in which workers have a supervisory role and perform manual tasks to finalize the product. The company also integrated a tracking system for materials and operations using barcodes. HYVUM is an innovative-oriented organization and has partnerships with universities to improve product quality and sustainability. HYVUM employs about 90 employees.

Case E (EVERYONIC a fantasy name): This is a production unit located in Italy of an International electrotechnical organization producing electrical switches. EVERYONIC automated part of the assembly line through cobots, which cooperates with workers to assemble the entire product and automated forklifts that automate logistic operations. Also, a manufacturing enterprise system has adopted to integrate organizational units. EVERYONIC maintained in place the manual assembly line after the development of the I40 assembly line. EVERYONIC is the leader of a manufacturing cluster for the deployment of I40 plants in Italy. EVERYONIC serves as a proxy for studying pilot projects that other organisations eventually adopt in the cluster. EVERYONIC employs about 850 employees.

4.4 Data collection

The study employs various data sources, both qualitative and quantitative, which are then triangulated to increase the reliability and reduce the subjectivity of the study (Denzin, 2006; Yin, 2018). For the data triangulation, I followed Denzin's (2006) principles that claim to conduct various methods to collect pieces of evidence of the phenomenon. Then, I compared these data, and I analysed whether the findings are conflicting or supporting the same pieces of evidence. Thus, I reached a more transparent and accurate analysis to explain social phenomena (Mills et al., 2009). Table 4 summarizes the data sources for each case.

Cases	Data Sources		
	Observations	**Key informant Interviewees**	**Secondary data**
A	Traditional assembly line, I40 assembly line, R&D unit	CEO, CPO two supervisor workers of assembly line workers one R&D responsible worker	official balance statements, official website, web interviews and articles
B	Traditional assembly line, I40 assembly line, automated warehouse, traditional warehouse	CPO, CQO two supervisor workers of the production unit one responsible worker of automated warehouse	official balance statements, official website, web articles
C	Traditional assembly line, I40 assembly line, IT units, product development units, warehouse	CEO, CIO, CHRO one supervisor worker of the assembly line unit	official balance statements, official website, web articles
D	Traditional assembly line, I40 assembly line, warehouse, administration unit, IT unit	CIO, CPO one supervisor of production unit workers	official balance statements, official website, web articles
E	Traditional assembly line, automated assembly line,	COO, CPO,	official balance statements, sustainability balance

Cases	Data Sources		
	Observations	**Key informant Interviewees**	**Secondary data**
	I40 assembly line, warehouse, logistic unit	two industrial engineers, two mechanical maintenances, quality manager, three informatic engineers, public relation officer, supply chain/operation engineer, two supervisor workers, two workers products engineer	statements, official website, web articles

Table 4 Data Source

The primary data sources of the study are semi-structured interviews and observations of I40 innovation transcribed in field notes. I used a flexible interview track centred on five themes which I slightly adjusted for each different role of the interviewed: (1) type and extension of the use of I40 technologies; (2) details of the traditional production process; (3) details of I40 adoption process; (4) consequences for the production processes afterwards I40 adoption; (5) workforce and management concerns of I40 automation. In Appendix, Table 26 and Table 27 present in detail the interview track for workers and management.

I opted for semi-structured interviews because this method allows for spontaneity, flexibility and open-ended responses from participants for more in-depth information. This method also enables the emergence of novel facets of the phenomenon (Yin, 2018).

In each case, I interviewed key informants (Kumar, Stern, Anderson, Stern, & Anderson, 1993), which are the management acting as the steering committee of the I40 adoption. And workers and their supervisors operating on the assembly line before and after the adoption of I40 technologies. I decided to include these two groups of key informants to have a more transparent representation of I40 adoption and its sustainable value creation. Because the voices of the two groups often diverged (Sawyer & Jarrahi, 2014) on themes related to how work conditions changed after the technology adoption and the consequences of technology automation on the assembly line workforce.

The interviews were conducted face-to-face, recorded, and transcribed. For Case A, B, C, D, interviews vary from 10 to 45 minutes. For Case E, the interviews in total lasted for about eight hours, with varying lengths from 15 to 60 minutes each. All the respondents are males aged 40–60, except the CHRP and CPO of Cases C and D, as well as the industrial engineer, public relations officer, supply chain/operation engineer, one supervisor worker of Case E, who are females aged 30–50.

The significant difference in the number of interviews and interviewees between the cases A, B, C, D and E is because Case E is a large organization that adopted several I40 technologies. In contrast, the remaining cases are SMEs that adopted less I40 technologies. Moreover, the steering committee of Case A, B, C, D is composed of two managerial roles on average. In comparison, the steering committee of Case E includes 13 people of management as the I40 technologies were adopted by projects managed by different personalities.

I conducted these semi-structured interviews during an organizational visit that I performed for each organization.

The organizational visit was organized similarly in each organization. The management – the Chief Production Officer (CPO) or Chief Information Officer (CIO) – received me. The management presented the organizational mission, the organizational structure, the way of producing with the traditional production process, and the I40 innovation.

Then, one competent person of the management accompanied me to visit the traditional production unit, the I40 production unit, and related units where I40 technologies were adopted. For instance, in Case A, I visited the R&D unit, where ceramics mixtures for I40 production are created. In Case B, I visited the warehouse in the logistics unit, which employed I40 technologies automating warehouse operations. In Case C, I visited the IT unit, where I saw the functioning of the traceability systems and their rankings. In Case D, I visited the digital administration, which was integrated by a traceability system with the production process. In Case E, I visited the IT unit, which showed me the MES of the organization.

The organizational visits of Case A, B, C, D lasted approximately three hours each. I performed the organizational visit of Case A in December 2018, while the organizational visit for Case B, C, D was during 2019. Still, the organizational visit of Case E lasted two full days in November 2019.

During the organizational visits, I conducted observations that I transcribed on field notes. After the organizational visits, I spent time re-elaborating all the observations writing field notes with my computer or recording a long voice message, which I transcribed a few hours later at home.

Moreover, I collected several secondary data in the form of official balance statements and distinguished national newspapers articles. I employed official balance statements - and sustainability balance statements only for Case E – to acquire official information regarding the sales index, Earnings before interest, taxes, depreciation and amortization (EBITDA) index and employment level of the organizations before, during and after the adoption of I40 technologies. I gathered these reports through AIDA[3]. For Case E, I did not find financial information of the local unit but for the entire

[3] AIDA is an online database, owned by Bureau van Dijk, containing financial information of more than 500.000 Italian companies. AIDA has official balance reports of Italian companies of the last 10 years.

organization – that is a S.P.A. – and the Italian rule imposes to publish aggregate data of the whole organization but not for each local unit.

Moreover, I searched on internet articles from distinguished national newspapers articles regarding these organizations, which focus on the I40 innovation, the sustainable value creation of these technologies, the consequences that these technologies have on workers, and the employment level.

I started collecting these data before the organizational visits and afterwards. In that way, during the organizational visit, I already knew information about the organizations and their I40 adoptions. Thus, I asked for more precise questions. Moreover, I had the chance to compare my research findings with articles published after my organizational visit. For instance, I confirmed my study's result related to the growth of employment level in Case E by a report by the labour union that stated that the organization is hiring hire in the next three years 122 apprentices. The data became increasingly focused through this process until theoretical saturation was reached (Eisenhardt, 1989).

4.5 Data analysis

To analyse the data, I followed the principles of qualitative inquiry of grounded theory (J. Corbin & Strauss, 2015). The grounded theory had its origins in the 1967 book, The Discovery of Grounded Theory, by its co‒originators, Barney Glaser and Anselm Strauss. They developed a research methodology that systematically derived theories from empirical data (J. Corbin & Strauss, 2015). From its inception in 1967, grounded theory spread quickly as an accepted qualitative research method (Urquhart, 2001).

During the analysis, I followed the recommendation regarding the theoretical saturation, that is, the point in the research when all the concepts are well defined and explained (J. Corbin & Strauss, 2015). I analysed the cases proposing two levels of coding. The first coding represents first-level concepts, and second-level coding means categories that can aggregate these first-level concepts. In my research, I conducted data analysis for each case and cross-case analysis using computer-assisted qualitative data analysis software (CAQDAS) as a supporting tool. This software facilitates the grounded theory steps by recording, sorting, matching, and linking qualitative data, enhancing the efficiency of the data analysis process (Hutchisona, Johnstonb, & Breckona, 2010). Thus, it is considered a necessary tool for high-quality qualitative research (Bandara, Miskon, & Fielt, 2011).

I analysed and coded the materials afterwards, the organizational visits. Since these visits were in different period of times, I firstly analysed data from each case, identifying:

- The sustainable value on the three dimensions of the triple bottom line consequent to the I40 adoption.
- How the adoption of I40 technologies created sustainable value on the three dimensions of the triple bottom line.
- How the management addressed the tension of the social and economic aspects due to the increasing automation of I40 technologies.

For each case, I created a single research database joining the transcriptions of the primary and secondary data sources. Since the data were collected in different periods, I had the chance to re-analysed cases previously analysed in two circumstances:

- when a new concept emerged from the analysis of novel cases.
- when I received feedback from the discussion of my analysis against my supervisor, PhD board, PhD. Consortium, conferences, and presentations during my two visiting periods in Belgium and Norway.

When I finished analysing and coding all cases, I conducted a final analysis of them, merging all the data of primary and secondary sources in a single research database. In total, I coded about 39,000 words of interview transcriptions and field notes and 218,620 words of secondary data.

I conducted cross-case analyses, comparing the findings across cases. I explored similar concepts and relationships across cases, comparing the categories identified from each case.

I conduced the last analysis proposing and discussing the coding with my supervisor. The coding procedure stopped when my supervisor and I agreed on the results of the coding. I arrived at the findings after several iteration rounds and adopting a three-fold saturation criterion:

(1) no new concepts emerge from the data
(2) all the data sources could be coded with the set coding structure
(3) my supervisor and I agreed on the results of the coding

When there were conflicts in the accounts of the participants, I organized follow-up phone calls for clarifications. This happened for Case D and E. In Case D, I had doubts regarding the mechanical arm adoption, and I had a call with the CIO that helped the adoption of the technologies. In Case E, I had a call with one worker regarding how the I40 adoption supports the social dimension of the triple bottom line and the tension between the economic and social dimensions.

Table 5 illustrates the coding data structure used in the analysis. I also provide a sample of the coded materials from all cases in Table 28 in the appendix.

1st Level Coding	2nd Level Coding
Reduction of raw material usage	Reduction of energy usage and natural resources
Reduction of paper usage	
Energy saving	
Less faulty products	Reduction of waste and faulty products
Fewer damages on products along the production process	
Sustainable raw materials	More Sustainable Products
Wood from sustainable farms	
Flexible daily production quantity	More Efficient Production process
Increased output quantity	
Reduction of defect rate	
Increased control over the production process	
Reduction of lead-time	
Workers aware of their daily performance	
Less loss of order information	Better circulation of information
Increased Information flow among units	
More accurate Information flow between outbound logistics and suppliers	
Workers as machine supervisor	More responsibility for workers
Increased Task Autonomy	
Workers with novel quality assurance duties	
Increased task autonomy for workers	
Maintenance workers as a technology developer	
Assembly line workers with maintenance duties	
Fewer powders in the warehouse	Better Work Condition
Less sawdust close to the machine	
Fewer microplastics in the production process	
Reduced temperature on the assembly line	
I40 technologies in charge of unhealthy activities	
Reduced physical stress for workers	
More ergonomics workstation	
Workers with more knowledge of raw materials	Workers with proficient competences
Workers with more competences for each production steps	
Workers with proficient competences in the management of I40 technologies	
Competences increased by vocational courses	
Knowledge of technologies increased by training-on-the-job	
Knowledge of technologies increased by mentorship	
Competences increased by refresher courses	
Novel IT unit	New Business Unit
Novel Production Unit	
Novel R&D Unit	
Novel Administration Unit	
Augmented reality application facilitates maintenances activities	Simpler activities for workers
Simpler assembly activities	
Quick Job Rotation	Sustaining Knowledge of production process
Employing workers for cobots activities	
Altering workers between I40 and manual assembly line	
Tailor-made course for workers thanks to technologies	
Knowledge of the process increased by teamwork	
Reduction of repetitive activities for assembly line workers	Reduction of repetitive activities
Reduction of repetitive activities for maintenance workers	
Reduction of repetitive activities for logistics workers	

1st Level Coding	2nd Level Coding
Difficulties for workers to repair finished products	Knowledge reduction of the production process
Limited knowledge for assembling an entire product	
Lack of knowledge of cobots assembly activities	
Low knowledge of technology feature	Lack of digital competencies to handle I40 technologies
Lack of informatics competencies for the workforce	
Reduction of production activities for workers	Reduction of human activities
Cobots substitute one human workstation Reduction of production activities for workers	
Logistic workers no longer drive forklifts	
Reduction of routine maintenance activities for the maintenance unit	

Table 5 Coding data structure of the analysis

4.6 Trustworthiness: assessing the quality of qualitative research

Evaluating the quality of a qualitative study is challenging due to the lack of agreement on the quality criteria in the field (J. M. Corbin & Strauss, 2015; Pratt, 2009). Corbin & Strauss debated this point, illustrating several studies that can be used to this end. Thus, from that list, I chose quality criteria according to my philosophical orientation, which is interpretivism. Consistent with the choice of interpretive paradigm, I employed assessment criteria by Guba (1981). The author claims that the interpretive paradigm assumes a naturalistic set of methodological procedures contrasting from the positivism posture.

According to the author, trustworthiness offers the answer to this question in the context of naturalistic inquiry. Trustworthiness considers four research validity criteria: credibility, transferability, dependability, and confirmability (Guba, 1981).

Credibility concerns the rigour with which the research has been conducted. It depends mainly on the procedures of a study and how rigorously it is performed. Therefore, credibility assesses how well I have conducted the research in order to present trustworthy representations of the phenomena and contexts that I have investigated (Guba, 1981).

Transferability is concerned with the relevance of the study (Guba, 1981). It refers to the extent to which the findings of a multiple case study are analytically generalized to further situations that were not part of the original research (Guba, 1981).

Dependability deals with the consistency and stability of data in conducting rigorous research (Guba, 1981). Reliability assesses the extent to which the results and conclusions drawn from a case study would be reproduced if the research were conducted again (Mills et al., 2009).

Confirmability deals with the objectivity of the study (Guba, 1981). The research is objective when the findings are considered objective, whether they are unbiased, without preconceived answers, and describe the way things really are in the empirical case. Investigators act in an impartially way when they do not alter the findings due to their values, ideology, or similar perceptual distortions (Mills et al., 2009).

To assess the criteria above, Guba proposed several items that researchers should address each criterion that is summarized in Table 6.

Concept	**Item**	**Criterion**
Credibility	Prolonged engagement at a site and persistent observation	Researchers should spend an extended period at a site to overcome data distortions produced by the presence of researchers and to identify pervasive qualities as well as atypical characteristics.
	Peer debriefing	Researchers should have the opportunity to expose and test their growing insights into a "jury" of peers and deal with whatever questions they may pose.
	Triangulation and collection of referential adequacy materials (Triangulation is also a requirement for the confirmability concept.)	Researchers should employ referential material data related to the studied phenomenon. Furthermore, researchers should use various data sources to cross-check data and interpretations (Denzin, 2006).
	Members check	Researchers should check the result of the work with key informants.
Transferability	Do theoretical sample	Researchers should choose cases that ensure to maximize the range of information uncovered.
	Collect "thick" descriptive data	Researchers should collect accurate data that allows for the comparison of the studied context to another possible setting.
	Develop a thick description of the context	Researchers should clearly describe the context of the study in order to make judgments about fittingness with other settings possible.
Dependability	Establish an "audit trail" and a dependability audit	An external audit should examine the processes whereby data were collected and analysed and researchers' interpretations.
	Overlap methods	Researchers should employ various methods in tandem to collect data in order to overcome invalidities in individual methods.
Confirmability	Practising reflexivity	Researchers should intentionally reveal to the audience the underlying epistemological assumptions of the research design.
	Arrange for a confirmability audit	An external audit should examine the processes whereby data were collected and analysed, as well as researchers' interpretations.

Table 6 Criteria of evaluation for a qualitative research

In Table 7, I document the details about how I addressed Guba's criteria to assess my dissertation trustworthiness.

Concept	Item	How I assured this item
Credibility	Prolonged engagement at a site and persistent observation	I performed five organizational visits in different periods. For Case A, B, C, D, I spent 3 hours on the organizational visits and in Case E, I spent two days. Although the time can be considered short of having a deep understanding of the phenomenon, I addressed this issue engaged with the field of I40 for manufacturing repeating investigations and analysis in different cases to be familiar with how I40 is adopted in manufacturing and the consequent sustainable value.
	Peer debriefing	I presented the results of the research to both my supervisor, PhD. Consortiums, conferences, presentations during my two visiting periods, and PhD. Board of my faculty. During these occasions, my presentation was followed by a question and answer time where professors asked questions regarding the method I used and the analysis results.
	Triangulation and collection of referential adequacy materials (Triangulation is also a requirement for the confirmability concept.)	I acquired several sources of data. My primary source of data is semi-structured interviews conducted with key informants of I40 adoption in each case. Then, I gathered official information from official balance sheet reports about the sales, EBITDA, and employment levels of organizations. Also, I collected web articles from prominent web newspapers about these organizations. For the analysis of data, I triangulated all these data. To this end, I compared the data from various sources, and I verify whether they reach the same conclusion. Also, the integrations of these data gave me a more detailed picture of the phenomenon. I made it for all the cases. Thus, I increase the reliability of data and to reduce the subjectivity of my interpretation.
	Members check	I had a phone call with a key informant of Case D and E, discussing the doubts I had on data. For Case A, B, C, I check the results by comparing my data with several newspaper articles published after my interviews related to the cases. These were in line with my findings. Moreover, I checked the results disseminating the study results in a conference with experts in the field.
Transferability	Do theoretical sample	The study is based on five cases of manufacturing organizations adopting I40 technologies. For this reason, I consider them a valid place to collect "concepts not people" (J. Corbin & Strauss, 2015). Still, I interviewed key informants, doing observations of the I40 assembly line, and triangulated secondary data of the phenomenon in order to maximize the information uncovered.
	Collect "thick" descriptive data	My research is based on a vast amount of data. I coded 39,000 words of interview transcriptions and field notes and 218,620 words of secondary data. Moreover, I increased the reliability of data interviewing key informants of I40 adoption, that is, management members acting as the steering committee of I40 adoption and workers that operate both in the previous and in the new assembly line. Along with the case description, I include several quotes from the key informants that allow the reader to reach an independent judgment regarding the analysis (Dube & Pare, 2003).

Concept	Item	How I assured this item
	Develop a thick description of the context	The study's context is characterised by manufacturing organizations that operate in an Italian contest, where the government of the nation provides funds to buy I40 technologies and encourage manufacturing organizations to reduce environmental impact. Another trait of the context is that these manufacturing organizations adopted these technologies to act sustainability and increase the quality and customization of products.
Dependability	Establish an “audit trail” and a dependability audit	I addressed this criterion involving my supervisor in the data analysis. I acted as the first coder while he discussed with me the results of the coding. Furthermore, I received an external audit of my work-in-progress research participating at a PhD Consortium and submitting articles related to my study to conferences (Braccini & Margherita, 2019; Margherita & Braccini, 2020d).
	Overlap methods	I conducted and combined the interview method, mainly semi-structured interviews, observations, and document analysis. Thus, I reduce my findings' subjectivity.
Confirmability	Practising reflexivity	The importance of this recommendation is also raised by (Zalan & Lewis, 2004). In my thesis, I followed this recommendation presenting and debating my philosophical assumption, which is the interpretive paradigm, in the first subsection (3.1) of the research design. Also, in most of the presentations I performed during my PhD Period, I spent little time on this theme.
	Arrange for a confirmability audit	Part of the PhD dissertation has been published in trustworthy journals (Information systems frontiers and Sustainability), book chapters by Springer and conferences. Thus, the connection between data and findings should be sufficiently demonstrated (Braccini & Margherita, 2019; Margherita & Braccini, 2020b, 2020d, 2020a, 2021).

Table 7 Assuring the criteria for the quality of qualitative research

5 Case description and analysis

In this section, I illustrate the cases include in the multiple case study. Each sub-section shows in-depth the process with which an organization adopted I40 technologies. To present the cases, I follow the framework proposed by Markus and well accepted in the literature to show the technology adoption process accurately (2004). This framework has also been used in another multiple case study where is explained the I40 adoption process (Bzhwen A. Kadir & Broberg, 2020).

The framework advocates that researchers present the organization before adopting novel technologies to have a clear picture of the organization. Hence, I depict the organizational characteristics, how the production unit was – because it is the central unit impacted by I40 technologies –, how the traditional production process operated with conventional technologies and the issues that the production process had experienced.

Then, the framework claims to present the adoption process of novel technologies. In this phase, I show how the management chose and approve the I40 project. Then, I illustrated the adoption process of I40 technologies, where the target operating units start-up with the new I40 technologies and attempt to "shake-down" the problems that occur. The framework recommends presenting how innovation changes organizations. Therefore, I show how the I40 production process operates and the generated outcome. I also show information related to the sales, EBITDA, and employment level of before-during and after the I40 adoption extracted by the balance sheets of the investigated organizations. Along with the case description, I strengthen the narrative, including several quotes from the key informants that allow the reader to reach an independent judgment regarding the analysis (Dube & Pare, 2003). I conclude by presenting the analysis of cases.

5.1 Case A

Case A is a manufacturer operating in the sanitary ceramics industry. The ceramic industry shows low levels of innovativeness, low technological level of products, and resorts massively to artisan processes (Ruggieri et al., 2016). QUEMIC is a medium manufacturing organization with around 200 workers located in the Lazio region and produces bathroom ceramics with an innovative design, enduring materials. It is attentive towards environmental sustainability and innovation in the product and process. It is working within a cluster of ceramic producers, and it is in the top three most significant companies in the cluster.

"We invested a lot in innovations. Our Industry 4.0 plant is the first in our industry. These technologies allow us to use different materials for ceramics, so we can innovate the production. The innovations for chalk are saturated. However, these technologies make the ceramics process more difficult" (CPO).

QUEMIC sells more than 240 products in more than 120 countries. Exportations reached 65% of their sales. CEO of QUEMIC is the founder of the organization that is also in charge of the designing of new products. Figure 6 portrays the organizational structure of the organization before the adoption of I40 technologies. The organizational structure is mechanistic-oriented. The organization is characterised by a centralised structure where the direction for information processing and decision-making is top-down. The organization has a clear chain of command, and the tasks of employees are very specialized.

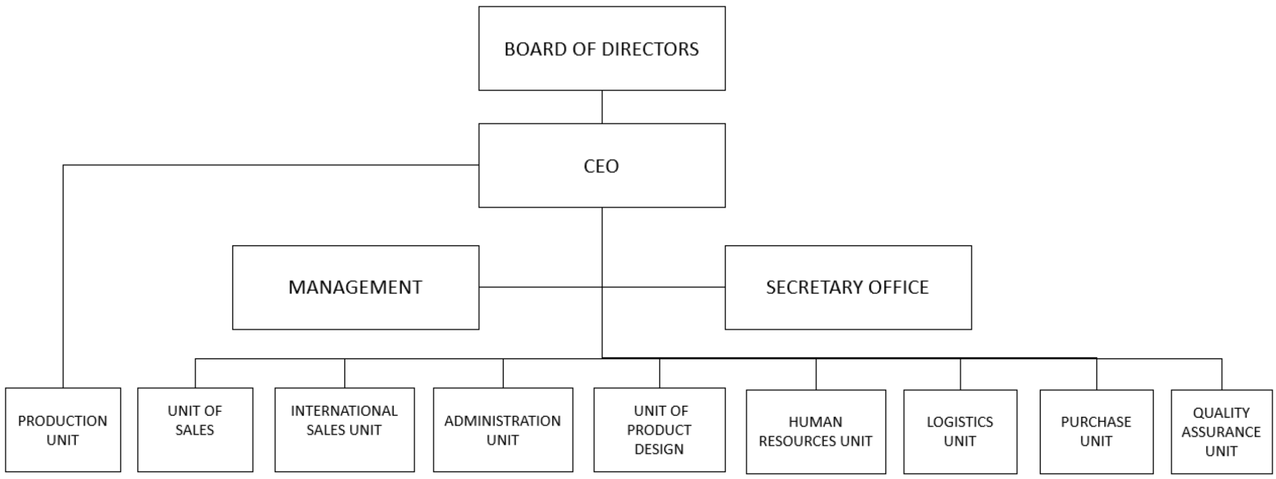

Figure 6 *Organizational structure of CERAMICS*

5.1.1 The traditional production process

The traditional production process consists of three phases: primary, secondary, and support. The primary phase encompasses all the activities for producing the goods, which begin from realising the chalk moulds, their drying, and modelling. During this process, workers manually operated machines and moved products and materials down the assembly line. The semi-finished products are then enamelled by high specialized workers in cabins and baked in the high-temperature oven (up to 1200°). The products that complete the process without any imperfections are moved to the warehouse by forklifts.

In contrast, products with defects are reprocessing in the secondary phase to address these production mistakes. Otherwise, products that cannot be fixed are destroyed and recycled. In the support phase, workers conduce all the preparation for packing and shipment of the products.

> *"This is the traditional production process. These are the moulds. This unit produces 150 pieces per day. One operator manages one machine. Everything is manual. At the end of the day, we switch on the oven for twelve hours to bake the products" (CPO).*

> *"This is the drying phase; workers equipped with a coverall and mask is drying the bathroom. This phase is critical, and we provide all the means to the worker to perform well and be safe" (CPO).*

The traditional production process was low efficiency and produced much waste. It also was labour-intensive and dangerous for the health of workers. During several production steps, workers were subject to inhaling soft powder (chalk). They also worked in a high-temperature environment (the working temperature of the oven is about 1200°) and carried heavy loads. These working conditions cause lung diseases and other kinds of traumatic diseases and create conditions for accidents. Any mismanagement in terms of handling the materials could decrease the quality of the product or increase the defect rate. Several products were damaged during the handling between the production and logistic units because workers do not drive forklifts at a moderate speed. Information about the production process was collected manually and was limited to the number of product outputs. Furthermore, the industry consumes a prodigious amount of energy, whose costs sum up to three per cent of the annual turnover.

> *"The traditional production process allows for high quantity with less quality of products. To produce that output, we have to do many moulds that became waste at the end of the process. Look, a singular mould costs 15000€. Then, the process had a problem along with the production and the movements of products" (CEO).*

> *"When workers drove the forklifts, they did not have a constant speed and many times workers have broken finished products they carried out" (CPO).*

> *"To understand how much is exhausting the ceramics production, we proposed to workers to operate also on Saturday only for that day. We had lots of orders. Although we pay well over time, they refused because they can't afford to work another day in a week" (CPO).*

5.1.2 The adoption process of Industry 4.0

QUEMIC switched from a traditional assembly line to a smart factory design using IoT technologies, robotic arms, automatic forklifts, mechanical arms activated by people, and control information systems in five years. CEO and CPO managed the I40 project.

The management planned the innovation and discussed the plan with all workers. The investment was necessary to guarantee the company's long-term survival in a market dominated by low-cost producers in developing countries with low labour costs.

> *"We don't want to import ceramics because we know how to produce it in a better way. Our strategy is to increase the quality of our products. If we import ceramics and we produce 5000 products less, I have to fire 50 people. For us, Industry 4.0 was the way to maintain stable employment and optimize the production" (CEO).*

The innovation significantly changed workforce operations and required workers with digital competencies. The company offered workers the opportunity to leave whether they were unwilling to learn new skills. All those who accepted were enrolled in vocational training courses throughout the five-year transformation provided by the technology developers. The vocational courses are focused on building digital competencies and skills needed to use the technology. These courses were provided by the external organization that developed the technologies.

> *"We hired two technology experts to automate the process and teach workers how to use the novel machines. We also help workers to understand the machine proving vocational courses outside the firm" (CPO).*

> *"Workers are happy with the new technology. They need an improvement in their way of production. Before, everything was manual. The work was hard, and the temperature in the plant was always hot. Now, their work is more mental than manual, and the workplace is better than before. We moved in the Industry 4.0 line, the expert workers who learnt more digital skills" (CPO).*

At the end of the production process transformation, the company kept in place the traditional process for small batch customer orders with limited quantities, which do not justify the high fixed costs of the I40 assembly line. Moreover, the traditional production process is used to train workers in the ceramic production process and to increase their knowledge in the technical aspects of the process itself. Workers are then moved from the traditional to the integrated assembly line when they acquired enough knowledge of ceramic production activities. Thus, they can contribute to improving the process and product.

> *"These apprentice for me is very smart. Now he is working on the traditional line, checking the values of ceramics components. He is learning the process at the manual level. When he pairs the number and results, I will move it on the Industry 4.0 line" (CPO).*

The innovation first required the redesign of the physical factory layout, as the I40 assembly line needs more space due to the use of several large-sized pieces of machinery. The factory was then equipped with autonomous machines—like self-driving forklifts, robotized arms, and fully automatic conveyors—to produce products and move them from one phase to another. In the end, all the machines were interconnected in an IoT system and governed by a control information system that keeps track of the data produced by the assembly line and allows the company to manage the production process flexibly.

> *"We were lucky because we have enough space for the new technologies, they are bigger than the previous ones, and the entire plant requires broader spaces" (CEO).*

> *"We have to track all the plan; thus, the forklifts can move autonomously and them we create a network in which we connect all these technologies" (CPO).*

5.1.3 The novel Industry 4.0 adoption process

Down the I40 assembly line, different robots perform the hard work of the process. Robotized arms produce semi-finished goods modelling the shape and moving the products on the automatic conveyor. Finished products are then placed on shelves and moved by autonomous fork trucks into the warehouse. In contrast, when workers mark the part as defective or damaged, the trucks deliver it to the secondary phase.

> *"This is the screen of the system that every week an expert optimizes. The system controls the robotized arms and automated forklifts. The forklifts are programmed to take and move the products in the warehouse. This is possible with an IoT infrastructure. The forklift understands where it is located and knows how to reach the selected places" (CPO).*

Along the line, the intervention of workers on the most massive phases of production is minimal. Generally, the workforce supervises automatic operations and continuously improves the process by fine-tuning the machines to reduce the defect rate and enhance output quality. Moreover, workers use their knowledge in ceramics production to suggest new settings for the machine to improve the process and the quality of the product.

> *"Now the workers have more mental duties than manual work. He is close to the robotize arms and controls the production process" (CPO).*

> *"We work safety. We only have to supervise the machine. Before, the work was tough. The machine also passes the ceramics to the forklift. We no longer have to take heavy products" (Worker 1).*

The I40 adoption also contributed to the digitalization of the design phase of the products. CERAMICS started to use CAD in order to design new product prototypes. Moreover, the I40 production process permits controlling several production process settings - such as production pressure and temperature. Also, the mechanical arms allow fabricating goods with different materials because they can manipulate and model various materials for creating bathroom shapes.

> *"The CEO designs the products with all the secret of our organization. Then we digitalized the projects with CAD. It is important because we can load it on the mechanical arms to produce the object quicker" (CPO).*

Thus, the management exploited these features settling an internal research and development (R&D) unit. The R&D unit continuously tests novel ways of producing ceramics with different materials and production and try to reduce the defect rate of products even further. Workers of the R&D unit attend vocational courses every six months.

> *"We settled the R&D laboratory. They search for a more sustainable and enduring mixture to use for our production. We hired workers to maintain the laboratory, and we provide vocational courses to them every six months" (CPO).*

Still, the CPO announced that the organization is planning to use 3D printings to improve the design phase making prototyping and testing more efficient and sustainable.

5.1.4 Outcome of the Industry 4.0 adoption

QUEMIC increased production by 30%, reducing the lead time and increasing the gamut of products offered to customers and their quality level. These technologies allowed the organization to govern the production processes, creating more practical and enduring products with a refined design. The substitution of human workers with autonomous robots took over all the physical work, contributing to reducing defects and damaged products. I40 adoption allows the organization to monitor the entire production process thoroughly. The tracking of the goods was ameliorated, reducing the order fulfilment inaccuracy. The data produced are continuously analysed, resulting in comprehensive reports on the machinery status and predictions regarding future production trends.

> *"Now, we integrate information flow through these technologies along the production process. With this technology, we reduced damaged products from 30% to 9%, maintaining the production constant without mechanical issues" (CPO).*

> *"This I40 application is the first in the ceramic industry. We risked a lot, but now our production increased by 30%. We increased control over the processes, and we also produce high-quality products" (CEO).*

The optimization of the production process also reduced the consumption of energy, water, and raw materials. The production process intensively reuses materials and resources. I40 contributes to building circular economy practices. The heat generated by the baking phase of the production cycle is re-used for the gradual cooling of the final product, reducing the energy consumption by the process. The automation of logistics units by means of automated forklifts reduced accidental damage of products which also reduced waste. The use of robots instead increased the precision of the steps performed during the production process, reducing the defect rate. At the same time as the I40 adoption, the unit also installed solar panels to produce electricity. I40 technologies continuously monitor energy production and consumption.

> *"The company has an ISO 14001 certification. They reduced usage of water, heat, and energy through an efficient production process, and installed solar panels" (Web article).*

> *"We recover heat from the oven in order to dry chalk moulds for the next phase saving energy. Also, we recover and reuse all the water employed in*

the production. We filtered this water; thus, we can use it for the next production" (CPO).

"We automate the handling of products by autonomous forklifts with a resulting reduction of damaged products that cannot be reprocessed and therefore, waste" (CEO).

The reduction of the defect rate contributed eventually to reducing waste materials and avoiding extra energy costs for the necessary repair phase of damaged products. Defective products which cannot be repaired are reused to the maximum extent possible, either as supports for the baking phase of conformant products, or as raw materials in the same process, or as raw materials in the construction industry (Ruggieri et al., 2016). Furthermore, the new production process allowed the company to sharply reduce waste of chalk moulds, metals (used only on the traditional assembly line) and muds. Thanks to the digitalization of the entire production process, the unit can design and test products. The redesigned products do not contain pollutants and use fewer resources (i.e., water in sanitaryware) during their daily life usage compared to traditional products.

I40 technologies also took heavy manual labour from the workforce, reducing the number of incidents and increasing workforce satisfaction. The worker duties increased. The workers act as supervisors and need new competencies, skills, and knowledge that they acquire through period training and vocational courses concerning the management and problem-solving in using the I40 technologies. The knowledge dimension of the work increased. On the assembly line, workers program the machines to be more efficient, avoid defects, and autonomously solve issues when they stop. They also provide feedback on any malfunctions of the I40 technologies to improve the production process. While in the R&D unit, workers study and try a more sustainable and enduring mixture for the production process.

"Workers thanks us for these technologies. Now, the worker is close to the mechanical arm. In case of mistakes of the mechanical arm, he can detect them and halt production. The temperature is now more adequate in the production process. While R&D workers have increased their knowledge of raw materials for ceramics thanks to vocational training and their experiments here, they are continuously testing new and sustainable mixture to produce ceramics" (CPO).

"Before we worked with a scorching temperature, now, these technologies improved our conditions mitigating the temperature. Now, I am supervising

these machines producing ceramics. The work I do now is less manual and more mental. I can activate and deactivate the machine, and I try to figure out if there is a better way to let it work" (Worker).

The traditional line availability also helps in transitioning workers to the new assembly line because they can be trained for the new production process while they retain their employment position. Thus, the organization could then defend the workers' positions, as many employees who possessed only artisan skills in the traditional production process remained in the company as operators. The I40 adoption contributed to separate all the dangerous health phases, such as the glazing process, that were entirely automated. The workforce can now act next to machinery pieces and far from dangerous phases in a much safer environment.

"I am making tests to find the best conditions for baking ceramic to improve quality. We will program the robots on the assembly line according to the parameters I will find" (R&D Worker).

"The company improves workforce conditions through I40. The worker has been requalified now they are technology experts. Now technologies move product in automation, and workers control the system through a computer. Case A also provides several vocational courses for workers" (Web article).

Table 8 shows the balance sheet of Case A, which undertook the I40 transformation in 2015. Afterwards, the earnings before interest, taxes, depreciation, and amortization (EBITDA) slightly increased. At the same time, the workforce remained almost constant after a decline at the beginning of the transformation in 2015.

	2018	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**
Sales	45.851.907 €	47.480.153 €	48.585.072 €	43.278.017 €	39.293.103 €	36.334.943 €	35.494.315€
EBITDA	12.984.069 €	13.269.796 €	14.933.236 €	11.293.393 €	8.147.484 €	6.123.442 €	36.334.943€
Net Profit	6.090.089 €	5.376.088 €	6.292.911 €	4.114.905 €	1.591.308 €	1.248.504 €	2.032.215€
Workers	223	233	224	237	237	267	284

Table 8 *Balance sheet report for Case A*

5.1.5 Analysis of Case A

The management of QUEMIC wanted to adopt I40 technologies because the traditional production process was low efficiency, labour intensive, and dangerous for workforce health.

The management planned to adopt the following I40 technologies: IoT technologies, robotic arms, automatic forklifts, mechanical arms. The management involved workers during the adoption process. They discussed the plan with all workers explaining how workers will change their operations and how these technologies improve their work conditions. The I40 technologies fully automate production operations which are conducted by mechanical arms and automated forklifts. At the same time, workers supervise I40 technologies, and they continuously improve the process by fine-tuning the machines to reduce the defect rate and enhance the quality of output.

Table 9 illustrates the sustainable value of I40 adoption in Case A, which are enabled by the automation of the production process, the provision of more accurate information, and worker activity as machine supervisors.

Sustainability Dimension	Outcomes of I40 technologies
Economic	A more efficient production process
Economic	Timely and accurate information
Economic	A more efficient logistic unit
Environmental	Reduction of raw materials
Environmental	Reduction of waste and faulty products
Environmental	Reduction of energy usage
Social	New organizational unit
Social	Workers with improved digital competencies
Social	Better work conditions
Social	More responsibility for assembly line workers
Social	Workers act as supervisor of I40 technologies
Social	Workers provide feedback to improve the I40 production process

Table 9 Sustainable Value Creation of Industry 4.0 adoption in Case A

Regarding the economic dimension, I40 technologies increased the production process efficiency, which resulted in a higher output of production by 30%, higher product quality and the possibility to produce a novel gamut of products. These improvements rely on the automation of operations along the production process, which reduced both the lead time and human mistakes along the line. Worker effort to supervise machines and spot improvements for the line helps maintain the production process efficiently. Moreover, the data retrieved from I40 technologies allows the organization to govern the production process better because comprehensive reports related to the machinery and production status are generated. The automation of logistics operations also reduced the time for order fulfilment. The improved process translates into improved economic performance, as companies can deliver high-quality, defect-free, customized products to the market.

I40 adoption is also beneficial for mitigating the environmental impact of the QUEMIC. The optimization of the production process reduced the usage of raw materials and energy because the operations by I40 technologies are more precise compared to the previous production process. The automation of logistic and production operations reduced the reduced accidental damage and defect rate of products, which resulted in less waste of production and the avoidance of extra energy costs for the necessary repair phase of damaged products. Also, by the report analysis of the machine status, the organization can prevent possible malfunctions on the line which consume energy and produce faulty products. I40 technologies help circular economy practices as they can couple with technologies to recover heat and water.

Moreover, I40 technologies positively impact social sustainability. Workers operate in a safer workplace with fewer powders and more appropriate temperature. They experienced empowerment. They are now in charge of actives related to the supervision of I40 technologies as I40 technologies carried on production activities by automating them. Thanks to these improvements, workers do not perform hard muscular activities and reduce workplace accidents and work illness.

Similarly, the logistic workers no longer drive forklifts but supervise the trips of the programmed forklifts. Moreover, workers acquired novel digital competencies through vocational courses. These competencies, coupled with a profound knowledge of the production process, make the experienced workers ready to work in an I40 context. In contrast, novel workers reached this level of expertise by training period on the traditional production line before working on the I40 production line. Also, management established a novel R&D unit to exploit I40 technologies, which required a novel job position entering the organization.

The case analysis reports three main tensions between the social and economic dimensions summarized in Table 10.

<table>
<tr><th>Social Sustainability Concerns</th><th>Organizational Response to social sustainability concerns</th></tr>
<tr><td rowspan="5">Reduction of human activities</td><td>Increasing duties for the workforce</td></tr>
<tr><td>Workforce performs novel creative activities</td></tr>
<tr><td>Increasing task autonomy for workers</td></tr>
<tr><td>New organizational unit</td></tr>
<tr><td>I40 technologies automate only labour-intensive activities</td></tr>
<tr><td rowspan="2">Lack of competencies to manage I40 technologies</td><td>Vocational training for the workforce</td></tr>
<tr><td>Easy-to-use I40 technologies</td></tr>
<tr><td>Reduction of knowledge of the production process</td><td>Interchanging workforce between traditional and I40 assembly line</td></tr>
</table>

Table 10 Managing sustainability tensions of Industry 4.0 adoption in Case A

The first sustainability tension is the reduction of human activities due to the increasing automation of I40 adoption, which makes the workers unnecessary in the units by conducting production and logistic activities. The organization addressed this tension by increasing the duties of workers responsible for monitoring the production process, supervising the I40 technologies and spot improvement opportunities to optimize the line. Also, the organization only automated labour-intensive activities, which resulted in better work conditions for workers. Moreover, by establishing an R&D unit, the organization create novel job positions.

The second tension regards the lack of digital competencies for working with I40 technologies expressed by workers. The management provides vocational training to solve this issue.

The third tensions regard the decline of workers' production operation knowledge, which is a requirement to understand whether the I40 technologies work in compliance. The organization maintained intact knowledge of the production process by interchanging workers between the I40 production line and the traditional assembly line to conduct production activities.

5.2 Case B

Case B is a manufacturer of custom kitchen furnishings that assembles standardized furniture parts to deliver kitchens configured on the bases of customers' needs. ALESWOOD is an organization located in the Tuscany region and has about 200 employees. ALESWOOD continues the traditional family business to craft modular kitchen parts since 1964. ALESWOOD has ISO 14001 certification and employs for their products only certified wood from sustainable forests. The industry of kitchen furnishings is seasonal, and it is mainly composed of several medium organizations. The traditional production process is labour-intensive and shows a low level of innovativeness on average. Organizations resort to seasonal workers to fulfil the demand in peak periods. Few organizations, among which ALESWOOD, are innovating the production undertaking I40 project because they afford to sustain a large investment. ALESWOOD aims to adopt I40 technologies to increase the quality and quantity of the production and fulfil the peak of production in a better way.

> *"ALESWOOD was born here, and thanks to our efforts now we have to plants…. Our market is seasonal. Generally, all the process to produce kitchen is manual, but we have problems to complete orders in the peak period…" (CPO).*

> "ALESWOOD *is environmentally friendly. They have an ISO 14001 certification and employs sustainable wood with FSC certification" (Web article).*

5.2.1 The traditional production process

The process is composed of two main phases: the production and assembly phases. ALESWOOD only produced by the traditional production process standardized kitchen components and purchased customized parts from external suppliers.

In the traditional production phase, a worker cut standardized components from a wood panelling with semi-manual cutting machines. Information on the process was in the form of paper-based bills of components that helped workers assemble the furniture. Workers took the elements manually and moved them down the assembly line. Then, workers moved components by forklifts to the assembly line placing them on a conveyor belt. In the assembly line, workers assembled the produced components adding the customized parts, which are produced by the external supplier and stored in a warehouse. Down the assembly line, there are several workplaces where workers assemble different products. Experience workers are capable of assembling all the products and helps each other to maintain constant the assembly phase. Workers delivered the products to the warehouse by forklifts that are then prepared to be shipped. The operations in the warehouse were manual.

> *"As you can see, this is the previous cutting machine we had in place. All the production is then passed by forklifts to the assembly phase, where workers assemble the components (CPO). All the information circulated with a list of the component. In the list, all the preparation is pointed out" (CPO).*

> *"This is the traditional assembly line; workers received the components and then assembled them. Along the line, we have many workers, and the most experienced workers can assemble all the products. The workers for us are jolly and helps the production to keep assembling" (CPO).*

The process was inefficient due to a high defect rate caused by the mishandling of materials and offered limited product customization possibilities. The work was physically exhausting, and part of the production environment was potentially unhealthy due to the presence of sawdust. Moreover, in case of a lack of customized parts for a product, the assembly phase cannot conclude the preparation, which provokes a slowdown of the assembly phase.

> *"Before this innovation, we relied on our external partners for the customized parts. So, if we don't have these parts, we can' conclude the furniture preparation. Moreover, the process was entirely manual and strenuous for workers" (CPO).*

5.2.2 The adoption process of Industry 4.0

The management decided to adopt I40 technologies to optimize the production process in order to increase the quality of products and reduce faulty products. The innovation purpose was to integrate the production unit and the logistics unit automating their operations by a mechanical arm, a digitally programmable sewing machine, an automated warehouse, and a manufacturing enterprise system. CEO and CIO managed the entire I40 project. ALESWOOD received national funds to begin the I40 transition.

> *"The purpose of innovation is to optimize our production and improve organizational processes. We need to reduce the waste in each production and be more organized" (CPO).*

With regards to the production process, the management undertook a pilot project with the producer of the semi-automated cutting machine, which was already in place within the organization, to develop a device that automates the cutting phase.

The producer built on a technology that combined mechanical arms and digitally programmable sewing machines that cut and prepare the kitchen parts to be sorted. The producer also provided vocational training in their organization – in Germany – because the documentation regarding the instructions and the machine's error resolution were not detailed.

An expert worker of the cutting phase of ALESWOOD spent six months attending vocational courses. The training courses provided the right digital competencies and the knowledge to operate with the machine. After this period, the worker was in charge of supporting the cutting machine adoption in the organization and teaching further workers to work with the machine.

> *"This machine is unique. It is a pilot project. The machine cut and move all the components we need for the kitchens, both customized and standard. The producer provides us also after-sale support because they don't have clear instructions and a list of problems that this machine could have. To use this technology, we sent one worker in Germany to follow several courses related to this technology" (CPO).*

With regard to the logistics operation, the management adopted semi-automatic conveyors down the assembly line that facilitates the handling of products. Furthermore, the management adopted an automated warehouse. The machine allows to automate the warehouse operation and check the availability of products thanks to an IoT infrastructure. The external producer provided vocational training to workers to teach them how to use the technology. Then a technology expert offered three month-period of on the job training to the logistics unit workers.

> *"We had a partnership with a produced of an automated technology. This warehouse is very innovative and permits to automate all the operations to store, check and move the good" (CPO).*

> *"We increase the speed of the assembly line by a conveyer belt that speeds the line automating logistics operations" (CPO).*

> *"Training on the job is essential. We have a guide to work with the technology, but workers need to understand how to work with a technology*

that does not block. The training on the job generally lasts three months" (CPO).

The two units and their technologies are interconnected by a manufacturing enterprise system (MES). The MES is also embedded on the TV screen along the assembly line that guides workers who manually assemble the product with visual instruction. Workers attended vocational training to learn how to work with the I40 technology. They acquire appropriate digital competencies and knowledge in the usage of the system. The innovation took three years, and the management established a novel product unit that employs the novel technologies.

"With this system, we can check our daily production and workers has a screen close to their workstation where they can see the digitalized bill of components and visual instructions" (CPO).

"Did you see the new production unit? It is in a different plant since it required more space than the traditional line. We adopted new cutting machines and an automated warehouse" (CIO).

5.2.3 The novel Industry 4.0 production process

After adopting I40 technologies, the cutting phase is fully automated through the employment of mechanical arms and digitally programmable sewing machines. This machinery is managed by an application that optimized the cutting phase, maximized the number of components obtainable from a standard wooden panel and reduced waste and dust. The technology allows the organization to produce customized kitchen parts in-house that previously were bought from suppliers. The mechanical arms move the components on a cart where workers control the quality of products. Then the cart is manually moved to the outbound phase, which is close to the machinery.

Still, the novel technologies are supervised by a team of workers. They check the production phases, product quality and specifications for the rest of the production process. Workers are also in charge of providing feedback to external organizations for improving the machinery operation as they have practical evidence regarding machinery malfunctions. Furthermore, the machinery continuously sends data of the production process to the producer, which provides after-sale assistance for the I40 machinery.

"The cutting machine is close in a cage. The machine has a sewing to cut the wood and a mechanical arm that moves the finished products. We produce all the components of the kitchen in-house now" (CPO).

"My team is supervising the machine. We are three workers. I am supervising the cutting phase and quality of products. While the other two workers supervise the mechanical arms" (Supervisor Worker 1).

"The technology is monitored in real-time by the producer by data send and a cam. In case of issues, we open a ticket, and the producer verifies the problems. They do maintenance analysing the production data related to the temperature of the technology and the production phases" (CPO).

The outbound phase of the production process was also automated, and the warehouse was equipped with IoT sensors. The movement of furniture parts in the warehouse is now autonomous. In the warehouse, the finished products are sorted and grouped according to customer order and the delivery destination to optimize space (5,000 components are now stored in the same space previously used to store 1,000 components). The automated warehouse is supervised by a worker that control the placement of products and its automatic operations.

"The automated warehouse is a tower of 13 meters. It is developed to optimize the space and to automate operations by robots and IoT sensors. Then, products are sorted to reduce trips of the distribution trucks" (CPO).

The assembly phase is still manual. Computer screens are used to show workers the assembly instructions, and semi-automatic conveyors present the components to the workers in the correct sequence to minimize the number of movements and simplify their work. Excluding those employed in the assembly phase, workers supervise the machinery, checking the production phases, product quality and specifications for the rest of the production process.

"The assembly line requires the same skill as the older one, but now each workstation has a screen that helps the workers and the conveyor belt that move the components" (CPO).

5.2.4 Outcome of the Industry 4.0 adoption

The innovation had several outcomes. I40 adoption optimizes resource usage and reduces production wastes. The MES allows optimizing each wood panelling cut producing as much part possible and reducing wood wastes. Moreover, MES allows the organization to digitalize the component bills and assembly instruction of components reducing the paper usage in the production unit. Exhausting and dangerous tasks were transferred to autonomous machinery, reducing work accidents and resulting in a safer environment free of sawdust and powder.

> *"The MES retrieves the orders and optimize the wood panelling saving wood, which came from certified sustainable farms. The MES integrates available parts. The production process now runs without interruptions avoiding energy waste. We also automated outbound logistic phase, and we group orders to reduce transports and movements within the organization—also, the automated warehouse help for this objective" (CPO).*

> *"The automated cutting machine passes the products to the mechanical arm, which drop then in a cart, reducing the number of damaged products" (Supervisor worker).*

> *"Look, the production technologies are inside this cage which blocks powders of productions and sawdust is sucked from that hole. The workplace now is cleaner" (CPO).*

ALESWOOD increased kitchen parts production because the automated cut machine allows fabricating also customized parts reducing the lead time. The technology produces 1000 components per working turn. Thus, the management sets a long-term goal to increase production by 20% in the next three years. The integration of the I40 technologies mitigates the damages during the movements of components, decreasing the damage products of the production.

> *"I40 application cuts move and store parts efficiently by an automated cutting machine, a mechanical arm and a pioneer automated warehouse. We now produce in-house all the goods according to the orders we received. On average, we produce 1000 parts per each working turn" (CPO).*

> *"The innovative production system, which the company is a pioneer in the adoption, is positively impacting economic performance, reducing time spent on each product production" (Web article).*

> *"This technology integrates the production process with the warehouse. We always now which available products we have in our warehouse. We also integrated outbound logistics with the supplier system; the supplier can send a suitable truck to transport the products" (CPO).*

Management requalified workers to operate in I40 production because the workforce activities are now more complex. Workers have greater responsibility, as they also act as machine supervisors. The automated cutting machine requires supervision in a team that facilitates the share of knowledge related to the technology among workers. Workers are also in the change of providing feedback to improve the machinery operation, as they directly experience how the machinery works. Experienced workers have an additional duty to teach younger workers to manage technology through on-the-job training. After the implementation of I40 technologies, the company had to employ more workers.

> *"I attended vocational courses for more digital competences. Now I place parts at the entrance of an automated warehouse, which store parts and I control the system in front of the computer before I moved and stored parts into the warehouse by forklifts" (Supervisor worker* 2).

> *"Before the work was 90% manually, we moved too many parts. Now I supervise the machine that does these hard tasks with two other workers. In contrast, before, I was alone. Now I have more responsibility as I check the quality of parts. I also teach my colleague to use this technology. In six months, he will be independent" (Supervisor Worker 1).*

Table 11 illustrates the balance sheet report for Case B. After the adoption of I40 technologies in 2017, the EBITDA increased along with the sales and profits. The number of workers also steadily increased as the improved quality of the products increased demand.

	2018	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**
Sales	106.860.231 €	106.852.829 €	95.226.687 €	84.353.953 €	78.028.435 €	73.069.252 €	74.128.291 €
EBITDA	8.514.515 €	8.434.987 €	6.225.339 €	4.714.540 €	3.170.375 €	3.079.452 €	2.924.582 €
Net Profit	4.245.683 €	4.509.915 €	2.439.406 €	1.394.957 €	454.426 €	7.799 €	79.445 €
Workers	203	187	179	170	163	160	159

Table 11 *Balance sheet report for Case B*

5.2.5 Analysis of Case B

Case B describes an I40 adoption that allowed the organization to produce in-house the entire range of their goods by automating the production process through the digitally programmable sewing machine, automated warehouse, and MES.

For the sewing machine, the management took part in a pilot project to develop a tailor-made technology for the production unit. The management involved a supervisor of workers before the technology adoption phase, who spent six months in the organization of technology developer following training to acquire the proper competencies to work with these technologies. For the remaining I40 technologies, the management purchased them from external provides.

The novel I40 production process sees the automation of the cutting phase and logistics activities. Along with these phases, the workforce supervises machine activities, checking the production operations and the quality of products. The assembly phase remains manual, and the computer screen facilitates the workforce tasks by providing visual assembly instruction.

Table 12 summarizes the sustainable value of I40 adoption in Case B, which are enabled by the I40 automation of the production process, more accurate information, and workforce activity that supervises the I40 technologies.

Sustainability Dimension	**Outcomes of I40 technologies**
Economic	A more efficient production process
Economic	Timely and accurate information
Economic	A more efficient logistic unit
Environmental	Reduction of raw materials
Environmental	Reduction of waste and faulty products
Environmental	Reduction of paper usage
Social	New organizational unit
Social	Workers with improved digital competencies
Social	Better work conditions
Social	More responsibility for assembly line workers
Social	Workers act as supervisor of I40 technologies
Social	Workers provide feedback to improve the I40 production process

Table 12 Sustainable Value Creation of Industry 4.0 adoption in Case B

Regarding the economic dimension, I40 adoption allows creating different kitchen furniture shapes from wood panelling. Thus, the organization can produce all kitchen components without delegating external suppliers for customized parts. Organizations can better manage the orders' fulfilment because they can produce all the parts that potentially lack in the warehouse. These automated machines also allow to create a higher output of products and reduce the damage products along with the line and product transportation due to human mistakes. The warehouse automation allows the organization to govern the available stock of products, reducing picking inaccuracy and increasing the storage space.

Regarding the environmental dimension, the I40 adoption allows for planning the cut of the wood panelling to reduce the waste of wood and obtain more kitchen parts. By automating operation activities, the organisation reduces the waste of production. Also, by using the MES, documents related to the instruction of product assembly and bill of components are digitalized, and therefore, the organization reduced the usage of papers.

Workers enjoy benefits from the I40 adoption. Workers act as machine supervisors, while I40 technologies automated production activities and logistics operations. Thus, workers reduced all the heavy activities related to handling products and conducting more knowledge-intense tasks. The automated cutting machine operates in a cage that blocks the leak of sawdust. Thus, workers experience a safer workplace. Also, workers learned novel digital competencies thanks to vocational courses. Experience workers also increased their duties because they teach younger workers to manage technology through on-the-job training. The organization established a novel production process to exploit the novel technologies which require the hiring of novel workers.

Social Sustainability Concerns	**Organizational Response to social sustainability concerns**
Reduction of human activities	Increasing duties for the workforce
	Workforce performs novel creative activities
	New organizational unit
	I40 technologies automate only labour-intensive activities
Lack of competencies to manage I40 technologies	Vocational training for the workforce
	Training-on-the-job for workforce
	Easy-to-use I40 technologies

Table 13 Managing sustainability tensions of Industry 4.0 adoption in Case B

The I40 adoption opens for two tensions between the social and economic dimensions (summarized in Table 13): workers lack proper competencies to work in an I40 context and the reduction of human activities along the production process. These tensions make workers unnecessary along the production line and allow the organization to fire them and hire a novel workforce. The organization addressed these issues, providing workers with vocational courses to teach workers digital competencies, requalifying workers with novel duties related to the supervision of easy-to-use technologies, and opening the novel production unit that requires more workers. Also, the organization only automated labour-intensive activities, which resulted in better work conditions for workers.

5.3 Case C

Case C is a textile manufacturing company. STYLORIUM is a small-medium organization of about 90 employees. 90% of the workers are female. STYLORIUM is part of an industrial district located in the Marche region, which has a long tradition of leather production. The organisation is considered very innovative as the management proposes courses to increase worker's skill of crafting leathers. And it is a supplier of luxury brands and produces several goods in leathers, mainly wallets, bags and trolleys. The production is labour-intensive and semi-automated. The technology for this industry can conduct only some parts of the production process because leather is an irregular material that needs a check before each production phase.

> *"I became the CEO a few years ago of this organization that is very traditional and has a long tradition of crafting leather" (CEO).*
>
> *"The leather should be touched before using it. It is impossible to automate this process. Each leather part is different from the others" (CPO).*
>
> *"Our production is 90% manual, and 90% of our employees are female. We only use machinery for some phase that can be automatized" (CEO).*

5.3.1 The traditional production process

The traditional production process was entirely by hand and structured in islands. It had three phases: in-bound logistic, production and assembly phases. The in-bound logistics phase includes all the activities needed to check raw materials for goods productions. The production phase consists of all manual activities to produce the goods starting from the cutting phase of materials, where workers reduce the thickness of leather by a cutting machine. Then, the preparation phase, where materials are joined. And the dyeing phase where semi-finished goods are dyeing, and the geometry of the products are created by a numerical control sewing machine. The production process ends with the assembly phase, where workers manually assemble semi-finished goods and perform quality assurance and prepare the packaging for products. Workers move semi-finished products along the assembly line by a cart.

> *"We have the production unit divided into three floors. On the ground floor, we have the acceptance of materials. On the first floor, we have the production unit and packaging, and on the last floor, we have the assembly unit. Each client of luxury brands has a dedicated assembly line. The*

organization is the same for each brand; the only thing that changes is the level of quality of the products" (CPO).

Workers circulated the component list along the assembly line. The workers used this paper to mark production progress manually. More specifically, the list of components lists shows all the raw materials and the assembly step to ultimate a product. Before the assembly, workers get a pack with all raw materials and the bills of components for the product to prepare. Workers check whether all the raw materials are in the pack and start the production marking the production phases and the time spent for each step.

> *"Here, you can see the workers that prepare a pack containing the components of a product and the list of components that are then passed to workers that conducts production operations. All these raw materials are checked before production. Thus, we know that our products use quality raw materials" (CPO).*

The process lacked accurate information on the time and quantity produced in each phase and total. The production, structured in islands, allows the organization to acquire information related to the daily production only at the end of the day. Thus, it was not possible to obtain accurate information on the real-time status of the production.

> *"Without industry 4.0 technologies, we do not control the assembly line. We don't exactly know the time spent for each preparation, and we cannot improve the process. Still, we have very few information on the process. We only know the product quantity at the end of the day" (CEO).*

5.3.2 The adoption process of Industry 4.0

STYLORIUM improved the process by adopting a traceability system with advanced analytics to measure the time spent on each production step accurately. STYLORIUM developed the system in-house and established an IT unit to manage and maintain it. The tracking system is embedded on a tablet down the production line. The granularity of data is at the microphase level and traces each worker phase and product. CIO managed the development and adoption of the traceability system. Furthermore, the IT and HR units developed a competence pattern and illustrations to facilitate each microphase production.

> *"We develop this system because we need to know accurately the time spent for each production. Our partner pays us a fixed price for each production,*

> *and we need to know if we have a margin with these preparation times. The technology aims a reducing production time and increases the quality" (CEO).*

The management informed the workers about the innovation project and provided vocational training to learn how to work with the traceability system. IT unit provides these professional training. The adoption of the tracking system was gradual. It was adopted in one production line at a time. The reaction of workers regarding the novel technology was adverse at the beginning because they do not afford to use the system. During the adoption process, technical errors happened, which made the acceptance of the technology more complicated. After the vocational training and the resolution of those technical issues, the technology was accepted positively by workers. Workers acknowledged the advantages of the tracking systems along the production line.

> *"When we developed the innovation. We had problems with workers that did not use it because they have a fear of making mistakes. But I could say that after some months they are enjoying this new system" (CPO).*

> *"The first impact of the tracking system was not positive. Now we positively accepted it, but at the beginning, there were a lot of technical problems. Also, we had a fear of making mistakes when we used the tablet. For example, we had a fear of going back or changed the mark of a phase" (Supervisor Worker).*

Moreover, the management involved expert workers in developing a learning path to teaching apprentices the competencies to work in the organization called "The Academy." The academy is an extended vocational course for 15 students, which is composed of five modules. The first three modules, glueing, dyeing and assemblage, aim at building the knowledge to work in the assembly line. The fourth module teaches apprentices to work along the assembly line. Thus, it focuses on organizational aspects and on digital competencies to use the tracking system. The fifth module regards quality assurance.

> *"We asked expert workers to track the needed competencies to work in the line. From this study, we develop the program for our academy. The academy has five modules: glueing,* dyeing *and assemblage, lean and quality. We create classes of 15 people, and we propose the academy every year. So far, we have developed 60 people. The novelty is that we teach a course on how to work in the line. We develop workers capable of working in each phase. At*

the same time, expert workers have an accurate knowledge of only one phase" (CHRO).

Then, apprentices that pass the exams for all the modules are employed on the assembly line, where they receive guidance from supervisor workers. The academy aims at developing workers capable of working in each phase of the assembly line.

"Our role is to teach workers and apprentices to understand the smiley. When it is red, we have a problem on the line, and we have to help the development of problem-solving skills" (Supervisor Workers).

5.3.3 The novel Industry 4.0 production process

The new process is structured in line, where each workstation is put side by side. Workers assemble the products in the traditional three phases and use a tablet that contains the traceability system interface and the target for production time and costs. The I40 production process remained manual but digitalized the bill of components that are embedded in the system. Moreover, communications among units are sent by the system.

"We now in line with workstation side by side, so workers can understand how the assembly process progresses. They have a table in front of each workstation where they input the time for the preparation" (CPO).

"The production structured in line allows us to intercept the problems while with the production in islands it is not possible because we cannot check in real-time the process but only at the end of production batch" (CPO).

"With this tablet, we check our productions and send communications to the other units in case of problems" (Supervisor worker).

The advanced analytics system produces performance statistics and displays them in real-time on TV screens on the assembly line. The TV screens show the targeted performance level with a green smiley face if on target or a red one if not on target.

"The system tracks the time spend for each production, providing statistics on workers and daily productions" (CEO).

"When we see the green smiley, we think that the daily production was good. When we see the red smiley, we understand that something goes wrong on the line, and we look for the problems" (Supervisor Worker).

Using reports produced by the data analytics system, the managers can identify workers who regularly perform below standards and discuss countermeasures to improve their performance, including the possibility of attending vocational courses, training to improve skills, or discussing the pace of the work. Workers who perform well receive extra compensation. Thus, the workers are motivated to complete the production steps in less time.

> *"Here, you see the tracking system. We have a ranking that summarizes how workers perform. Highlighted in green are workers who perform well, and in red, workers who perform below standard. For that, we propose actions to increase their performance" (CPO).*

5.3.4 Outcome of the Industry 4.0 adoption

The adoption of I40 delivers a more efficient production, better coordination among units, reduced waste, and a reduced defect rate. The time spent on production steps is accurately measured and also reduced. The tablet helps workers perform better by providing detailed visual instructions on the movements they need to perform to avoid mistakes. This improvement reduces the production mistakes that consequently decrease the leather lost and wastes during the production. The organization also reduced the paper usage along the production process as the system embedded the bill of components. It reduced the waste of time in search of the bill of components along the line. Thus, the system allows for better data circulation and communication among units.

> *"We required a technology that allows us to improve our crafting skills rather than to replace workers as this technology would be a replicable asset. Thus, we increased our production quality" (CEO).*

> *"Case C has become one of the most innovative companies in the leather industry. Case C increased production through an innovative production system" (Web Article).*

> *"The system improved data circulation among the organizations; we can now track the product advancements for each product. Moreover, we reduced leather wastes from productions, which our clients send us, through worker competencies because it is not possible to automate this process. Workers now always know the advancement of production; they do not spend time searching paper along with the production phase" (CPO).*

The workers can manage the tasks they perform by helping each other, in particular, to speed up underperforming lines. They are supported by the screens that show daily production trends in real-time and compare the trends with the target set for each day. The workforce also becomes more proficient in the competencies required for crafting leather through vocational training. In fact, apprentices acquire a specialisation over the entire production process, and experienced workers acquire competencies in different production steps and reinforced knowledge about the production steps they are in charge. Moreover, all the workers acquired digital competencies to use the tracking system. They know how to mark the time on the tablet for each preparation and control daily production. Workforce morale also increased after the I40 adoption because the TV monitor allows the workers to check the achievement of the daily production goals and how the team daily works.

> *"We self-manage the production with Tv monitors because now we know how much we produce per day. Also, the competence patterns in the tablet help to improve our works" (Supervisor Worker).*

> *"When we see the green smiley, we think that the daily production was good. For example, yesterday, the screen was broken, and I was worried about the entire day because we don't know the production. This innovation really helps us to know how well it is going the production" (Supervisor Worker).*

> *"The company won a price for the academy which intensified competences of workers through vocational courses and provided guidance for apprentices" (Web Article).*

> *"The production process remained the same, but now we can improve manufacturing because we can work in each phase of production and self-managed the unit" (Supervisor Worker).*

> *"The company won a price for the academy which intensified competences of workers through vocational courses and provided guidance for apprentices" (Web Article).*

> *"After the acceptance of these technologies by workers, their morale increases. They thank us because these technologies really help to improve the way of working" (CPO).*

Table 14 shows the balance sheet for Case C. Sales and EBITDA of the organization remained stable for the entire period. At the same time, the number of employees decreased before the I40 adoption in 2017 and rise in 2018.

	2018	2017	2016	2015	2014	2013	2012
Sales	9.729.992 €	10.898.420 €	8.063.020 €	7.635.606 €	8.509.532 €	10.039.060 €	9.460.818 €
EBITDA	515.170 €	620.941 €	283.911 €	338.536 €	301.233 €	667.140 €	607.607 €
Net Profit	181.053 €	251.571 €	57.168 €	59.879 €	62.447 €	207.621 €	200.271 €
Workers	90	86	92	93	93	94	96

Table 14 *Balance sheet report for Case C*

5.3.5 Analysis of Case C

Case C presents an I40 adoption that aims at governing the production process providing real-time information regarding the status of the daily production and the time spent for each preparation by a traceability system. Management set an IT unit that developed the tracking system adapting it to the organizational needs.

The I40 production process remained manual, but workers use tablets – that embedded the tracking system - to mark the time spent for each preparation and view the digitalized bill of components and assembly instructions. By retrieving data from the system, the organization creates reports regarding worker performance statics and daily production.

Table 15 summarizes the sustainable value of I40 in Case C, which is enabled by the I40 automation of the production process and the provision of timely and accurate information.

Regarding the economic dimension, the organization experienced a more efficient production process because the production support activities were automated. Workers reduce the lead time of operations and production mistakes thanks to the tablet, which provides visual instructions to produce the goods and automate the production support activities. The use of traceability systems makes a more efficient circulation of information among units, positively impacting the production. Workers can consult the list of components on the tables without losing time searching the paper-based list of components.

Sustainability Dimension	Outcomes of I40 technologies
Economic	A more efficient production process
Economic	Better circulation of Information
Economic	The use of tablets facilitates workers' task through pictures and production patterns
Economic	Empowerment: increased task autonomy for workers
Environmental	Reduction of raw materials
Environmental	Reduction of waste and faulty products
Environmental	Reduction of paper usage
Social	Workers with improved competencies/knowledge of the entire production process

Sustainability Dimension	Outcomes of I40 technologies
Social	Continuous improvement of worker competencies through tailor-made vocational training
Social	New organizational positions/units
Social	Workers with improved digital competencies
Social	Better work conditions
Social	More responsibility for assembly line workers

Table 15 *Sustainable Value Creation of Industry 4.0 adoption in Case C*

Also, by checking the production status, workers can manage their tasks by helping each other to speed up underperforming lines in complete autonomy. These improvements translate for the organization in the opportunity of the organization to better serve the market with increasing output of quality products.

Regarding the environmental dimension, the I40 adoption contributes to reducing the waste of leather because the system guides workers and the operation with a resulting reduction of faulty products. This technology also reduces the usage of paper along the line by digitalising all product assembly instructions and the list of components.

I40 adoption positively impacts social sustainability. Workers work in a more stimulating work environment and stress-free because the tracking system allows workers to check whether they are working on time or whether they have to speed the production. Moreover, workers acquired are more competent to craft leather thanks to vocational training because they gain expertise for each step of the production process. Also, the tracking systems allow maintaining a high level of their knowledge of production steps because it detects those workers performing below standard. The management provides vocational training to those workers to build proper knowledge of the production process. They also acquire digital competence to deal with the tablet. The organization also hired new staff that are employed in the IT unit.

The case analysis reports two main tensions between the social and economic dimensions, which are summarized in Table 16. The first sustainability tension is the reduction of human activities due to the increasing automation of I40 adoption, which conducts support activities – the filling work of the list of components.

The organization addresses this tension by automating production support activities and increasing the duties and autonomy of workers who are now in charge of maintaining constant production, helping each other speed up underperforming lines and less repetitive tasks. Workers are supported by screens showing the daily production trend in comparison with the target set for the day. Also, the organization opens new job positions for the novel IT unit.

Social Sustainability Concerns	Organizational Response to social sustainability concerns
Reduction of human activities	Increasing duties for the workforce
	Workforce performs novel creative activities
	Increasing task autonomy for workers
	New organizational unit
	I40 technologies automate only repetitive activities
Lack of competencies to manage I40 technologies	Vocational training for the workforce
	Easy-to-use I40 technology

Table 16 Managing the sustainability tensions of Industry 4.0 adoption in Case C

The second tension regards the lack of digital competencies for working with I40 technologies expressed by workers. To prepare workers to work with this technology, the organization developed a series of vocational courses – the so-called "Academy" –to teach digital competencies to and reinforce the expertise to work in the line for novel works. Experienced workers conduct various training courses to become familiar with the tracking systems.

5.4 Case D

Case D is a historical small-medium manufacturer of orthopedic prostheses with about 90 employees located in the Lazio region of Italy. HYVUM was founded in 1974. The main customers of HYVUM are patients with a physical disability, and HYVUM receives orders both from public health and from private patients. The employment of chalk characterizes the production of orthopaedic prostheses to build the good. The products are highly customized in order to meet the needs of disabled patients. HYVUM has an ISO 9001 certification.

5.4.1 The traditional production process

The traditional production process of HYVUM is composed of three phases: prototype, production and test phases. In the prototype phase, the orthopaedist visits the patient and develops the prosthesis project. The prosthesis project contains all the detail to build a definitive prosthesis for the needs of patients.

> *"We have both internal and external orthopaedists that prepare the prosthesis project, which is then realized in our organization down the assembly line" (CIO).*

Down the production phase, the workforce uses the prosthesis project as a guide to producing the prosthesis. In this phase, workers firstly build the mould from a solid block of chalk. It is then passed to workers, which customized the prosthesis manually according to the customer's requirements. Workers employ several utensils and add metallic support to finish the prosthesis creation. The prosthesis is then covered by a thermo-expanded and a resin layer. In the test phase, the patients try the prosthesis, which is then and refined by workers to improve the ergonomics and improve the clients' range of motion to the maximum extent.

> *"In the previous production process, all the productions were manual. Workers performed all the activities from the solid block of chalk to the customizations. In each step of preparation, workers have to accomplish some microphases to finish the step. Some preparations are more standardized than others" (CIO).*
>
> *"The patient is invited to the organization and tries the prosthesis. They try to do all the movements that are not possible without the prosthesis. A doctor supervises the operations and checks problems if occur" (Web Article).*

Workers employ a production sheet to manage the production phases for each prosthesis. Each worker marks the time spent on each preparation. It also provides information to orthopaedists in case of delay in the production of the prosthesis. This production process has characterized by a dirty work environment because the chalk preparation produces powders. Moreover, the traditional production process has an unpunctual measurement of time for each preparation step and a lack of information regarding the prosthesis production advancement because workers often lost the production sheet or did not mark phases on the production sheet. This lack of information also hampers to deliver a bill with the prosthesis imposing disability patients come several times to the organization.

> *"We manage all the production process with a production sheet where workers have to check whether they complete the operations and write the time spend. In reality, all the workers check the preparation and standard time of 15 minutes. We cannot improve the process with this method" (CPO).*

> *"The production process consists of modelling a chalk mould and, of course, the preparation generates powders. These preparations are monitored with this sheet, but this method is not performing for us. Because lots of time we lost this sheet, and we cannot say the status of the prosthesis and neither we cannot give information to the doctors" (CIO).*

5.4.2 The adoption process of Industry 4.0

The management decided to improve the process by the adoption of mechanical arm and traceability systems. CIO and CPO support the external producer to adopt the technologies in organizations. The mechanical arm employs a milling system expressly aimed at the orthopaedic industry, allowing the creation of chalk mould for the production of a custom prosthesis. The mechanical arm realises the prosthesis following a project developed by intuitive CAD software.

> *"XXX is a robotic milling system expressly aimed at the orthopaedic industry, allowing to create any model (positive or concave) for the production of orthoses and custom prosthesis" (Web Article).*

> *"The heart of the mechanical arms is our software. It is able to simulate all the production steps completely, and allows companies to generate CAM tool paths on geometries coming from digitalization and external CAD systems, and use specific CAM operations for the orthopaedic field" (Web article).*

The tracking system provides timely information regarding the production process, measuring the time for each production phase through an identification system based on a barcode scanner and an integrated digital billing system. The tracking system is embedded on a tablet down the production line. Thus, the tracking system allows integrating the administration and production unit.

The management anticipated the implementation of the tracking system to the workers. The workforce reaction was adverse initially because they have difficulties using the tablet to mark the production phase. But the reaction changed positively when workers experienced a decrease in problems related to the advancement status of the products. The adoption process was gradual. They started adopting these technologies for more standardized preparation of the production process.

> "*Initially, workers' reaction towards the adoption of these technologies was negative; they don't want to change their routine to mark the production process. Workers said that the table slowed down the work. But it changed in positive when they understand the improvement of the systems" (CPO).*

> *"We adopted these technologies in production phases more standardized. Then we passed in the remaining phases. In the standardized phases, the acceptance was easier because works have to open and close the phase. While in the remaining part, they also have to choose on the system the part they are operation" (CPO).*

During the adoption process, workers attended vocational training to employ I40 technologies that developed I40 technologies. The courses aim at teaching digital competencies and how to use the software of mechanical arms. The management also settled a new unit called digital administration, hiring two people, which is in charge of managing the digital billing system switching in digital all the clinical history and bills of the patients.

> *"We arranged several courses for workers to teach how to use the software of the mechanical arm and the tracking systems. The courses were taught by the organizations that developed the technologies" (CIO*).

> *"We settled the digital administration unit which digitalized all the paper-based documents and created bills. Thus, we can check the clinical history and bills of our customers easier" (CPO).*

5.4.3 The novel Industry 4.0 production process

The new production process is semi-automated. A worker initializes the robotized arms, which following the CAD project, develops the initial shape and surface of the prostheses in a separate room. Then, the workers refine the prostheses manually. The workers supervise the mechanical arms, which increased production flexibility, reduced chalk use, and thus improved working conditions.

> *"The workers that supervise the mechanical arm operated in the assembly line. Now they have new duties. Workers now have skills to use the machine and artisanal knowledge to create the prosthesis" (CIO).*

> *"The mechanical arm is in charge of the first part of the prosthesis production. It performed faster than people improving productivity, and reduce time spent on production. The worker now is a supervisor of the technology" (CPO).*

Along the production process, workers employ a tablet to mark the start and finish time for each production step using barcode scanners. The system gathers data from the production process and provides real-time information to orthopaedists and descriptive statistics to the management. The system data are integrated into the digital billing system, which delivers a bill when the prostheses are finished. Along the production process, paper usage is reduced.

> *"We adopted these tabled embedded the tracking systems which manage the production phases for each order. We made faster the data input with an intuitive interface" (CPO).*

> *"The tablet with the tracking systems interconnects the organization providing statistics of the production process. The application measures better our processes, particularly production advancement" (CPO).*

5.4.4 Outcome of the Industry 4.0 adoption

The information flow and traceability of the process are now improved. The system allows the organisational units and orthopaedists to know the advancement of the preparations in real-time. Moreover, the accuracy information helps orthopaedists with subsequent prosthesis modification because the system stores the clinical history of the patients. Thus, the organization provided a better service for the patients and orthopaedists that increased their satisfaction.

“Now, we always know the advancement status while before we had to find the worker who had the bills. Whether it was in the administration or in the production units, it was hard to find this information. Now this system allows us to know the status of the production and, in case of production issues, we know who made it; or manage the preparations which takes too much time” (CPO).

I40 adoption increased efficiency through the tracking system because the workers do not waste time manually reporting information. Also, the possibility of making mistakes has been reduced. Workers can now just focus on improving product quality. The system also optimized the process of ensuring alignment between technical information about the protheses and administrative billing information for customers. The usage of paper decreased thanks to the tracking systems drastically. Workers experienced a safer and cleaner workplace because there is less powder down the production process as the robotized arm is in a separate room.

“Clients are more satisfied with the prosthesis after we adopted these technologies; we know it by administering surveys. We increased their quality and also the service that we offer” (CIO).

“The system allows us to control the production process automatically. We made it faster because now the workers only operate on the prosthesis without considering other tasks like to move the bill of order” (CPO).

“We automate the first part of the prosthetist production, with a mechanical arm in a separate room. Now the workplace has fewer production powders (CPO).”

Table 17 illustrates the balance sheet for Case D. Before adopting I40 technologies in 2017, the EBITDA and sales remained almost stable, while the workforce number growths by 30 units in five years. Following the I40 adoption in 2017, EBITDA and net profit increased by 65% and 97%, respectively, whereas the number of workers increased by two units.

	2018	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**
Sales	16.967.339€	17.229.166€	16.822.189€	16.731.097€	15.556.783€	14.634.219€	13.702.293€
EBITDA	1.502.983€	907.456€	1.164.817€	1.011.499€	962.919€	1.463.312€	847.169€
Net Profit	810.412€	410.249€	285.092€	319.416€	284.311€	21.606€	144.815€
Workers	99	97	91	79	78	75	61

Table 17 Balance sheet report for Case D

5.4.5 Analysis of Case D

Case D provides evidence of an I40 adoption that semi-automates the production line by a mechanical arm and a traceability system to increase the efficiency of prosthesis production and govern the advancement of the prosthesis preparations. The management adopted these technologies gradually and set the digital administration unit to integrate the administrative information flow with the technical one. The novel production process begins with the robotized arm developing the initial shape and surface of the prostheses, which are supervised by workers. Then, workers eventually refine the prostheses manually and mark the time spent for each preparation on the traceability system.

Table 18 shows the sustainable value of I40 adoption in Case D, which are enabled by the I40 automation of the production process, the provision of timely and accurate information, and worker activity as a machine supervisor. Regarding the economic dimension, by automating the first stage of the production process through the mechanical arm, the organization experiences a more efficient production process. The production workflow remains constant thanks to the supervision of workers on the mechanical arm. The use of the tracking systems supports the economic dimension because it allows for a better circulation of information within the organization.

Sustainability Dimension	Outcomes of I40 technologies
Economic	A more efficient production process
Economic	Better circulation of information
Economic	The use of tablets facilitates workers' task through pictures and production patterns
Environmental	Reduction of raw materials
Environmental	Reduction of waste and faulty products
Environmental	Reduction of paper usage
Social	New organizational positions/units
Social	Workers with improved digital competencies
Social	Better work conditions
Social	More responsibility for assembly line workers
Social	Workers act as supervisors of I40 technologies

Table 18 Sustainable Value Creation of Industry 4.0 adoption in Case D

Tracking systems help the organization have real-time information about the production process, resulting in a better service for the customers. Still, workers better operate as the tracking systems provide picture and production patterns to facilitate the operations. Also, tablet usage, which guides workers to conduct their production activities, has reduced worker mistakes during their operations.

The adoption of I40 technologies also contributes to mitigating the environmental impact of the organization. The digitalization of the bill of components reduces paper usage in the organization. The mechanical arm also reduces the use of chalk compared to traditional production. Therefore, the conjoint effort of I40 technologies and workers improve the production process, which resulted in less faulty products and production waste.

Moreover, I40 adoption is beneficial for social aspects. Workers operate in a safer workplace because part of the production process is conducted in a separate room by the mechanical arm. Thus, there are fewer powders down the production line. Workers reduced manual activities but took on new duties operating as supervisor of the mechanical arm. Still, the digital administration unit has been established to exploit the I40 adoption, which requires novel job positions to enter the organization.

The analysis revealed two tensions between the social and economic dimensions, which I summarize in Table 19. The first tension is the lack of competencies to manage the mechanical arm and the tracking system that may push the organization to fire the workforce and hire more specialized workers. The organization addressed this issue by teaching how to use and work with these technologies by vocational training.

Social Sustainability Concerns	**Organizational Response to social sustainability concerns**
Reduction of human activities	Increasing duties for the workforce
	Workforce performs novel creative activities
	Increasing task autonomy for workers
	New organizational unit
	I40 technologies automate only labour-intense activities
Lack of competencies to manage I40 technologies	Vocational training for the workforce
	Easy-to-use I40 technologies

Table 19 Managing the sustainability tensions of Industry 4.0 adoption in Case D

The second tension regards the reduction of worker activities due to the mechanical arm's automation, which makes workers not necessary along the line. The organization addressed this tension, creating novel activities for workers. The organization increased increasing the duties of workers. They are in charge of refining the prosthesis and supervising the mechanical arm, which automated labour-intense activities. Also, the novel digital administration unit required new workers entering the organization. And, the organization only automated labour-intensive activities, which resulted in better work conditions for workers.

5.5 Case E

Case E is one production unit located in the Lazio Region of Italy of an International electrotechnical organization. EVERYONIC produces electrical switches of various dimensions through automated and manual assembly lines. EVERYONIC was founded in 1979 and currently employs about 850 employees, of which 80% are blue-collar and 20% white collar. EVERYONIC is a worldwide leader in automation technologies in different sectors. And a leader of an Italian manufacturing cluster for the development of I40 applications. EVERYONIC serves as a proxy for studying pilot projects that other organizations eventually adopt in the cluster. EVERYONIC has the following certifications: ISO 9001, ISO 14001, and OHSAS 18001 for occupational safety.

The global electrical switch market reached a value of US$ 7.6 Billion in 2019[4]. There is a significant rise in the need for upgrading electrical transmission networks, especially in emerging economies, on account of rapid urbanization and increasing population. Thus, the market has been experiencing growth in the last years. The market is dominated by multinational organizations, such as ABB Group, Alstom SA, Eaton Corporation Inc., and General Electric Company.

5.5.1 The traditional production process

In the manual production process, EVERYONIC produces small electrical switches. The process is structured in islands where each worker prepares the components and manually assembles the entire product in several steps following preparation lists created according to customers' orders. The process consists of the pre-assembly phase and assembly phase. In the pre-assembly phase, the worker builds components for the assembly phase. In the assembly phase, workers employ different utensils, such as soldering machines, and perform electricity and temperature quality tests on products. The logistic is also manual. Workers place the finished products in packages marking the production line batch, and then the products are moved to the warehouse by forklifts. When workers find problems with machines, they inform the line supervisor, which calls the maintenance units by phone opening a ticket. When the customer claims a faulty product, the organization provides after-sales assistance, and workers detect the production issues and fix them.

> *"Here, you can see the assembly line structured in islands. On this side, the worker has all the components for the switch. He assembles the switch, and then he conducts quality test for the electricity, temperature and so on. Here,*

[4]Circuit Breaker Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2020-2025 https://www.imarcgroup.com/circuit-breaker-market retrieved: 10/08/2020

he does not have the screen which says the daily production. He knows only at the end of the turn the production. Then, they conduct after-sale assistance on these switches" (CPO).

"In the traditional process, we have only these automated machines for the quality test. We need to know if the electricity passes into the switch and the temperature with which the switch works. Before the logistic was completely manual, a worker drives the forklift" (Industrial Engineer).

Before the cobots, the workers do this repetitive pre-assembly phase and all the preparations. It was structured in islands and not in line and each worker does an entire product" (Mechanical Maintenance 1).

The manual process lacks accurate information on output and time. These pieces of data are self-reported by workers that fill excel files at the end of their shifts. This self-reporting mechanism is also in use for maintenance reports. The data are eventually used for compiling production statistics. The lack of precision on information reporting creates frequent and recurring coordination problems between production, logistics, and maintenance. The maintenance unit was not punctual to fix the mechanical issues, which hampers the line to continue the productions. Packages were lost during the handling between the production unit and the logistics unit. Moreover, in the pre-assembly phase, several production issues occurred due to the repetitiveness of operations. These issues forced workers to de-assembly the parts and assembly them again.

"In the traditional process, we use Excel for the production quantity and other data. We use them to do statistics. But it was difficult to improve the production with this method because it was difficult to find the problems and workers fall from the skies when we talk about the production problems of yesterday" (CPO).

"With the traditional process, each worker counted the production switches at the end of the turn. We don't know how the production was and how workers perform. And this was negative for the workers because they work with uncertainty. They had fear not to reach the production goal…. Another problem was the call to the maintenance that always spend 20 minutes to come and blocked the line… The pre-assembly phase is repetitive, and workers had only to attach some components and often the errors happened in this phase" (CPO).

5.5.2 The adoption process of Industry 4.0

The management undertook a participatory approach (Mumford, 2003) to improve the assembly line, launching a survey for workers seeking to receive their advice regarding how to improve the production process of the manual assembly line. By considering the survey results, the management eventually decided to adopt a set of I40 technologies: semi-automatic conveyor belt with smart sensors, robotics, augmented reality application, traceability system, data analytics, manufacturing enterprise systems (MES). Each technology was developed and adopted by different projects. The steering committee of the projects vary. Table 20 presents in detail the people of the steering committee for each I40 project. The management also involved workers during the adoption process. They selected the most expert workers with digital skills.

> *"We started with the Industry 4.0 projects in 2017. We asked workers to imagine how these technologies can change our firm. So, we launched a survey in the entire organization, both blue and with collar, asking whether they know these technologies and their thought about our firm. Based on the survey results, we knew that many workers knew these technologies and already used them, such as 3d printings. We continued organizing some projects to develop these technologies, including workers with digital skills. For example, the maintenance unit programmed the cobot movements that we purchased from an external producer" (COO).*

The management purchased from technology experts both cobots, smart sensors and automated forklifts. The maintenance unit programmed the movements of cobots and smart sensor systems for semi-automatic conveyor belts. The logistics unit, supported by engineers of the operation unit, programmed the automated forklifts. The industrial engineering unit cooperated with a technology developer for the AR application. The IT department developed the advanced MES, data analytics and the tracking system, integrating the data of the different technologies with granularity at the level of production steps.

Working Position	Role
COO	He managed the entire I40 project.
CPO	He managed cobot adoption.
Two Industrial engineers	They managed the development and adoption of I40 technologies, particularly the augmented reality application.
Two Mechanical maintenances	They managed the development and adoption of cobots movements, its vision system and smart sensor system.
Quality manager	He managed the data of the I40 assembly line.

Working Position	Role
Three Informatic Engineers	They managed the development and adoption of the advanced manufacturing enterprise systems and the data analytics and tracking system.
Public Relation officer	She supports the management of the entire I40 project.
Supply Chain/Operation Engineer	She managed the development and adoption of the I40 logistics and supply chain system.
Products engineer	He managed the industrialisations on the I40 assembly line of new products.

Table 20 Steering committee of the Industry 4.0 projects

> *"Each project was composed of white and blue-collar that aimed to develop and adopt a king of Industry 4.0 technologies. When we don't have this expertise and know-how in the organization, we created a partnership with external organizations and start-up" (COO).*

> *"Our workers develop all the projects and in some cases with external firms. We have lots of expertise on the automation, so we afford to develop these technologies" (Public relation officer).*

> *"My team – IT unit – developed all the applications from the MES to the tracking system. This is the MES…. We also integrated all the new technologies. The project was challenging, but we succeed. This is a best practice for our corporation" (Informatic Engineer 1).*

The technology adoption was incremental and started in 2017. The management discussed the innovation plan with all the workers to comprehend how their way of working would have changed. The workforce reaction was initially adverse towards the cobots and automated forklifts because they completely replaced some roles. The feedback turned positive after the workforce experienced their tasks were made simpler by the I40 technologies.

> *"The adoption of cobots was difficult to digest for workers. Initially, they argued against the cobots because we reduced one human workstation. But we don't reduce the number of employed workers. Now, they really accept the cobots, and they don't want to work without them. Workers needed time to adapt to the new production and the new technology" (Mechanical Maintenance 1).*

> *"At the beginning, the workers had difficulty working in the new line. They considered the technology negative for their work because they now conduct fewer manual activities. But now they accept them. They are enjoying less repetitive work with more supervision tasks" (CPO).*

The management provided vocational courses for the workforce to acquire proper competence to deal with I40 technologies, particularly the cobot. The training courses include lessons that explain how to use the technologies and address the most common errors. Training on the job and mentorship were additionally provided to acquire knowledge in the I40 utilization. At the same time, additional training courses are also focused on teaching how to use the AR application. The courses explain how to use the application, the interface and the sections where are contained the instructions. Periodically all workers receive training on the latest updates of the I40 technologies.

> *"For each technology, the management provided courses. Our workers do not have digital competencies, and we need to build them. They are so crucial that now are a prerequisite to work in our organization" (CPO).*

> *"The experienced workers attended a lot of courses regarding novel technologies. They are very different compared to the classical technologies. Here we have to supervise their operations" (Supervisor worker 1).*

> *"We taught the interface of the application, how to use the feature of the maintenance and the part related to the instructions that we digitalized. By the way, the application is intuitive and easy to use" (Industrial engineer 2).*

The innovated assembly-line is semi-automatic and shorter. Thanks to the use of the I40 technologies, one workstation disappeared with the previous tasks which are performed by machines. The assembly line works with a strong interplay between the cobots and the workers where repetitive activities are passed to cobots while workers supervise the technologies. The manual assembly line remained in business, structured in islands, where the workers perform repetitive activities assembling complete products. The manual assembly supports the I40 assembly line to reach the daily production goals and repair defected products received by customer-assistance. Moreover, how the MES schedule the sequence of products minimizes the repetitiveness.

Nonetheless, the workforce expressed concern regarding knowledge reduction on how to assemble the products. Also, how EVERYONIC trains workers to perform the assembly activities privileges the human production steps neglecting the assembly phase performed by cobots. Workers also had difficulties in addressing assembly issues of finished products or when faulty product come back to the firm.

> *"The traditional production process pushes workers to know all the activities of the entire production process while with this new line workers know only a small part of the production process….Workers do not know well the*

production process, especially activities to repair the products…. Since cobots assemble product constantly, we firstly teach how to assemble manual phases. Then in case of cobots problem, we teach the cobot phases" (CPO).

"In the traditional line, we knew which product we assembled, I made it, and I know how I assembled it. If there are some problems and customers send it back, I can understand my errors and improve my way of assembling. Now, it is possible because I only put some parts of the switch, and in case of errors, we don't know who made the errors. We only do movements, not assembling" (Workers Supervisor 1).

"In the end, this way of producing consists of only repetitive activities and not a production like in the traditional method" (Worker 2).

The management addressed the concern with a frequent rotation of jobs along the I40 assembly line and rotating workers between the I40 and the manual assembly line. Thus, workers perform various assembly activities, that increase the level of knowledge of the assembly phase of the entire switch and on how to fix faulty products. Still, when cobots have difficulties in assembling components (due to different shapes or weight of switch components), the workers perform the task in the place of the cobot. The workers are rotated daily to mitigate the negative effect of repetitions and increase their knowledge on the assembly of the entire switch and on how to fix faulty products.

"We decided that a good way to solve this problem was with a quick job rotation on the line. Thus, all the workers do something different every day (CPO) and can conduct activities to assemble products. Then they conduct the pre-assembly line when the cobots are off" (CPO).

"Now, we know in a better way how to assemble the entire products, because we are interchanging between the new and the previous line" (worker 1).

"For example, we use now components with a different weight, and cobot does not work properly. To speed up the line, we employ workers for cobots activities" (Mechanical Maintenance 1).

5.5.3 The novel Industry 4.0 production process

The I40 production process begins with MES retrieving orders from the corporate ERP. Down the assembly line, TV screens display orders with real-time performance statistics visible to all workers.

The workers prepare the product components placing them on semi-automatic conveyor belts that carry them on the cobots workstation. The workers manage the cobots – cobots need to be started and stopped and need manual intervention in case of failure picking – and the cobots conduce the pre-assembly phase of the switches with several repetitive activities. The workers supervise the cobots addressing simple mechanical issues, and finalize the product with the assembly phase. The workforce also conducts the remaining customisation steps and performs quality control of the assembly of the previous worker before starting her assembly activities. The assembly line components are tagged with barcodes tracked by the traceability system that automatically measures the time spent for each phase. In case of defects, one worker will manually rework the product on a separate island.

The workers on the assembly line received training to address simple mechanical issues of the machinery that they fix in autonomy with the assistance of AR applications. The application provides them with visual step-by-step instructions. For more complicated issues, the workers call the maintenance unit. At the end of each maintenance, the AR application automatically sends a report where workers can add further comments. This data is acquired by the MES and used for statistics on maintenance.

The finished products are moved to the logistic unit through an automated forklift, which is controlled by logistics workers.

> *"The process starts here. This worker loads the components for the cobots. The cobot assembles these components then are workers by the reaming people of the line. When a worker is free, she helps the line to perform better" (CPO).*

> *"Workers have to supervise the cobots because it has a problem picking the components whether they differ in weight. Generally, the supervision is required because also the powder can create issues" (Mechanical Maintenance 1).*

> *"This is the automated forklift; now it is moving a package from the line to the warehouse. All is automated, but logistics workers control the machine" (Product Engineer).*

5.5.4 Outcome of the Industry 4.0 adoption

I40 innovation produced several outcomes for EVERYONIC. The automation of the pre-assembly phase prevents all the common assembly mistakes of the workers. Moreover, the lead time is shorter than before, and consequently, the production doubled, passing from an average of 400 to 800 switches produced daily. The defect rate of the assembly phase is also reduced to the point that management sets a quality goal of 250 defect pieces per million for produced switches. The reduction of defect rates also decreases the waste of products in plastic.

> *"The gain of I40 line was a constant production. We reduce lead time and assembly errors by cobots, and we reach 800 pieces per day while before we only produced 400 pieces" (CPO).*

> *"We increased the productivity of the line with the cobots which assemble a part of the switch components faster than workers. Also, the MEs help us reduce the time spent to find the customer's order" (COO).*

> *"We set challenging quality goals related to faulty products since the production drastically reduced defects rate. We are also reducing wastes from the production with this innovative production" (Quality Manager).*

Teamwork also contributes to maintaining the production constant because it helps build a better knowledge of the production process. Workers can discuss their issues and share ideas on how to improve their skills. Since each worker acts as a quality controller against the colleague work, the workforce develops analytical skills to potentially fix faulty assembly activities and help co-workers perform the activities better.

> *"Now the production is on the team. After the work of the cobots, each worker assembles part of the switch. They also check the quality of the assembly of the previous workers. Thus, they can solve potential problems and discuss the error with the colleague" (CPO).*

As a result of the data collected on the performance of the assembly line, EVERYONIC could reduce the cost for energy and prevent common mechanical issues on cylinders of the conveyor belt that may cost 1500€ each in electricity per year. The smart sensors allow verifying whether a maintenance intervention on the conveyor belt was successful by comparing performance data before and after the interventions. This improvement also contributes to maintaining constant production. The combined use of the MES and the AR applications sharply reduced the consumption of paper.

"With the smart sensors, we can prevent the break of cylinders. We esteem that a damaged cylinder cost us 1500€ in electricity. Still, with smart sensors, we can check if the maintenance of cylinders was good comparing the data before and after. Thus, we reduced energy waste" (Mechanical Maintenance 2).

"With the AR application, workers do not bring all the manuals of the machinery to do maintenance, they have a digital copy in the application, and it is faster to read it thanks to the search function" (Industrial Engineer 2).

"We already use the ERP to acquire the orders digitally. With these new technologies, we digitalized all the documents of the maintenance by the AR application and the schedule of the orders by the MES. Thus, we have reduced the papers" (Informatics Engineers 1).

The coordination among the units is also improved. The maintenance workers reduced intervention time from 20 minutes to 9 minutes on average. Through the reports produced by the data analytics system, the management can set challenging quality goals – the threshold of faulty products, daily production quantity – to improve the production and monitor the progress to reach them.

"All the units are integrated with the MES, and the management has real-time data of the production. We know the daily production and the status of the production" (Informatics Engineers 3).

"With the AR application, we reduce the intervention time from 20 to 9 minutes. Now each worker can call the maintenance before they have to call the supervisor, which opens a ticket for the intervention." (Informatics Engineer 2).

"When we use the paper-based system, we have coordination issues because sometimes bills of orders were lost. While with the MES, we integrate all the units. Now we work to integrate our partner of the supply chain" (COO).

Workers enriched their duties. Although workers of the assembly line reduced their manual activities, they have more supervision activities related to machinery management. Indeed, cobots require to be activated and stopped in case of errors. Moreover, when product components are changed, cobot struggled to perform assembly activities, and workers helped them take the components correctly.

Also, assembly line workers conduct simple maintenance activities on the line thanks to the guidance of AR application and quality control activities as they check the assembly of the previous worker.

Moreover, workers have increased autonomy. They can manage the activities they perform, helping each other's – particularly to speed up underperforming lines –. Also, they make these decisions with the support of screens showing the daily production trend in comparison with the target set for the day.

Similarly, workers of logistics units are now in charge of supervising and managing the trip of the automated forklifts while previously they were in charge of driving the machine. The maintenance unit also increased their duties because they are in charge of scouting novel technologies during the adoption process. Still, they program the cobots beyond to maintain them operative. They also have increased autonomy.

> *"Now, the worker can directly order the broken piece through the AR app to conclude the maintenance. Before, workers had to call the maintenance unit" (Informatics Engineer 2).*
>
> *"In the new assembly line, we workers download the order from the MES, we change components on the line, we help each other to maintain constant the production. They are more autonomy" (Supervisor Worker 2).*
>
> *"My unit, the maintenance, did scouting of these technologies, and then we programmed the cobots and vision system. Before, we only fix machines. While assembly line workers have to supervise the cobot, which has micro collisions, and their work is very important. Sometimes cobots break the piece of the vision system has problems. They afford to restart or block the system. They help each other and charge components on the line" (Mechanical Maintenance 1).*
>
> *"With AR application, workers conduct simple maintenance activities because the AR application does visual instructions for the maintenance and it also contains all the book of instructions" (Industrial Engineer 2).*
>
> *"Now workers supervise the cobot. Before, they only perform manual operations, and now, they are a sort of technician. It is a great improvement for them. Along the line, the worker performs quality control of the assembly of the previous worker" (CPO).*

"We used workers with knowledge on Industry 4.0 technologies to study and develop the application of these technologies, and they also did a sort of scouting. They also do focus groups with universities and start-up…. Now the workers that operate with cobots supervise these robots using a computer. They can block them or restart them. While logistics workers now manage the forklifts" (COO).

Furthermore, workers enriched their competencies. Thanks to the vocational courses, workers acquired digital competencies to use novel technologies. Training-on-the-job and mentorship conclude the workforce training straightening knowledge of production activities. The workers can start, stop, and restart technologies. Moreover, the mechanical unit obtained from the experience of the I40 project the competencies to program cobots.

"EVERYONIC provides several vocational courses both for using cobots but also to work in the new assembly line. We provide them to apprentices and for experience workers periodically" (Public Relation Officer).

"We received courses to manage the cobots. We learned how to block the robots and how to restart it. Then, we taught us also the most common mechanical errors of the cobots" (Supervisor Worker 2).

"For the maintenance unit was a challenge to program the cobots. We followed a course for coding. This coding skills and our knowledge of machine anomalies really helps us to set up the cobots. We also created the system to prepare the components for the cobots" (Mechanical Maintenance 1).

"We received training on the job to use the cobots. Three supervisor workers provided mentorship to us to improve our competences in the use of the cobots" (Worker 1).

"Now workers of the assembly line know better all the activity phases and how to manage cobots thanks to training on the job and fast rotation. The work is less repetitive" (CPO).

Moreover, through the reports produced by the data analytics system, managers identify workers regularly performing below standards and discuss with them countermeasures to improve the performance, including the possibility to attend tailor-made vocational courses, train or discuss the pace of the work on the process. Still, a maintenance worker can verify whether upkeep along the assembly line is successful through the data analysis of smart sensors.

> *"The tracking system allows us to find in which assembly phase workers perform below standard. Thus, we propose courses to increase skill and knowledge for those phases" (Quality manager).*

The redesign of the I40 assembly line also increases the safety and health of the workplace, with a resulting reduction of job accidents. Workstations are more spacious and ergonomic. Workers sit distant from the cobots that, assembling the products, produce microplastics that are no longer inhaled by the workforce.

> *"The redesign of the line makes the workstation more organised and ergonomics, thanks to Industry 4.0. The workstations are larger than before, and workers are more comfortable with movements. We also reach the golden zone for the picking. We adopted shelving units along with the I40 assembly, which also assures safe handling between 50-120 cm" (Supply Chain/Operation Engineer).*

> *"Along the line, cobots automated an assembly phase releasing microplastic. Now the line is safer because these microplastics remain in the cobots area, and the worker does not inhale them" (Mechanical Maintenance 1).*

The last balance sheet of 2018 of EVERYONIC states that the organisation has 858 employees. According to the CPO, the number is the number grew about 100 units compared to the employment level of seven years ago. Adding to this, in the following three years (2020-2022), they will recruit 122 apprentices.

5.5.5 Analysis of Case E

Case E illustrates an I40 adoption that transforms a manual assembly line into a semi-automated assembly line by introducing a semi-automatic conveyor belt with smart sensors, robotics, augmented reality application, traceability system, data analytics and MES. The management chose these technologies thanks to the support of workers who proposed technologies to improve the production process and their work conditions. Maintenance workers helped the code of cobots movements to automate the pre-assembly phase, which was the phase unhealthy for workers – due to the creation of microplastics – and where human errors were common – due to the repetitiveness of operations. The adoption process was incremental.

The I40 assembly line starts with the MES, which retrieves the orders. A cobot, supervised by workers, assembles the first stage of the assembly, which are finalized manually by workers. Workers are also in charge of addressing simple mechanical issues of machines by the guidance of the AR application. The finished products are moved to the logistic unit through an automated forklift, which logistics workers govern.

Table 21 illustrates the sustainable value creation of I40 adoption in Case E, which are enabled by the I40 automation of production process, the provision of timely and accurate information and the activity of workers that act as machine supervisor.

Sustainability Dimension	**Outcomes of I40 technologies**
Economic	A more efficient production process
Economic	Better circulation of information
Economic	A more efficient logistic unit
Economic	The use of tablets facilitates workers' maintenance activities
Economic	Empowerment: increased task autonomy for workers
Environmental	Reduction of raw materials
Environmental	Reduction of waste and faulty products
Environmental	Reduction of paper usage
Environmental	Reduction of energy usage
Social	Workers with improved digital competencies
Social	Better work conditions
Social	More responsibility for assembly line workers
Social	More responsibility for maintenance workers
Social	Workers act as supervisors of I40 technologies
Social	Continuous improvement of worker competencies through tailor-made vocational training

Table 21 Sustainable Value Creation of Industry 4.0 adoption in Case E

Regarding the economic dimensions, the interplay between I40 technologies and workers double the output of production as the usage of cobots automate repetitive operations, which reduced lead time of pre-assembly operations avoiding common human mistakes. Thanks to the MES, information circulates among units more efficiently, diminishing intervention time on the line and resulting in a more constant production line. Similarly, workers contribute to maintaining stable production by working in a team on the line and acting as a quality controller. The possibility of fixing the mechanical issue by the workers helps to keep optimizing the performance of technologies on the line. Therefore, these process improvements translate in economic value for the organization as it can fulfil more customer orders thanks to a higher quantity of products. I40 adoption further stems from the environmental impact of the organization. By the data analytics, workers can prevent the mechanical issues of conveyor belt cylinders saving energy. Still, MES and AR application allows workers to read a digital copy of machine instructions, and this feature contributes to reducing the paper usage along the line. Also, decreasing human mistakes in logistics and assembly activities of products reduces faulty products, which often became waste.

I40 adoption supports social sustainability. Workers enjoy a safer workplace, free of microplastics and with ergonomic workstations, resulting in reduced job accidents. Workers also acquired novel digital competencies because of vocational training, mentorship, and training on the job. Workers have more responsibility as they take on quality assurance activities, supervision activities of I40 technologies and their maintenance by the guidance of AR application. Similarly, maintenance workers reduce simple maintenance activities but take on activities related to the development and scouting of novel I40 technologies.

The logistic workers no longer drive forklifts but supervise the trips of the programmed forklifts. Also, I40 technologies, particularly the traceability systems, contribute to increasing the knowledge on production activities of workers because it allows monitoring workers performing below standard. Thus, management can enrol them on vocational courses to teach the proper operations to improve their performance. The organization hired workers both during and after the I40 adoption.

The analysis revealed three central tensions between the social and economic dimension (summarized in Table 22). The first tension refers to the lack of digital competencies to work with I40 technologies. The lack of competencies may lead to the layoff of workers, which are not suitable for the line Organization prevented this circumstance by providing vocational courses, training on the job and mentorship for the workforce to build proper competence to deal with I40 technologies which are easy-to-use.

The second tension regards the reduction of human activities along the line because cobots automated part of the production line that workers previously performed. The organization addressed this tension, increasing the duties for workers, which now supervises the cobots and maintain constant the line helping workers of the underperforming lines.

Social Sustainability Concerns	**Organizational Response to social sustainability concerns**
Reduction of human activities	Increasing duties for the workforce
	Workforce performs novel creative activities
	Increasing task autonomy for workers
	I40 technologies automate only repetitive activities
Lack of competencies to manage I40 technologies	Vocational training for the workforce
	Training-on-the-job for workforce
	Mentorship for workforce
	Easy-to-use I40 technologies
Reduction of knowledge of the production process	Interchanging workforce between traditional and I40 assembly line
	Fast job rotation for workforce along the assembly line

	Teamwork facilitates knowledge build-up
	I40 technologies support actions to increase knowledge of the production process

Table 22 Managing the sustainability tensions of Industry 4.0 adoption in Case E

The third tension refers to the reduction of the level of knowledge of assembly activities which was decreasing due to the I40 automation. The organization supports the workers in maintaining a high level of knowledge of assembly activities by a fast job rotation and interchanging them between the traditional and I40 assembly lines. Thus, they can conduct the entire assembly activities, which resulted in straightforward activities. Similarly, the teamwork and the conduction of cobot activities when they are offline are further actions the build-up of the knowledge of the production process. Also, the tracking systems help support a high level of knowledge production, detecting those workers performing below standard, to which they are provided vocational training to increase their expertise.

6 Findings

In this section, I illustrate the results of the analysis of the multiple case study. In the first sub-section, I illustrate the sustainable value creation of I40 adoption on the three dimensions of the triple bottom line. In the second sub-section, I present how I40 adoption supports the three dimensions of the triple bottom line simultaneously by describing the I40 enablers. In the last sub-section, I explore how organizations of the cases address the tensions between the economic and social dimensions due to the increasing automation delivered by I40 technologies.

6.1 Sustainable Value Creation of Industry 4.0 adoption

Table 23 summarizes the sustainable value creation that I40 adoption delivers on the three dimensions of the triple bottom line simultaneously for the case companies. Several outcomes are consistent across all the cases, while others are particular to just some.

Case(s)	**Sustainability Dimension**	**Outcomes of I40 Technologies**
All	Economic	A more efficient production process
All	Economic	Better circulation of information
A, B, E	Economic	A more efficient logistic unit
C, D	Economic	The use of tablets facilitates workers' task through pictures and production patterns
E	Economic	The use of tablets facilitates workers' maintenance activities
C, E	Economic	Empowerment: increased task autonomy for workers
All	Environmental	Reduction of raw materials
All	Environmental	Reduction of waste and faulty products
B, C, D, E	Environmental	Reduction of paper usage
A, E	Environmental	Reduction of energy usage
A, B, C, D	Social	New organizational positions/units
All	Social	Workers with improved digital competencies
All	Social	Better work conditions
All	Social	More responsibility for assembly line workers
E	Social	More responsibility for maintenance workers
A, B, D, E	Social	Workers act as supervisors of I40 technologies
A, B, E	Social	Empowerment: workers provide feedback for improving the I40 production process
C	Social	Workers with improved competencies/knowledge of the entire production process
C, E	Social	Continuous improvement of worker competencies through tailor-made vocational training

Table 23 Sustainable value of Industry 4.0 technologies by sustainability dimension

Concerning the economic dimension of the triple bottom line of sustainability, the results show in all cases that the adoption of I40 technologies delivered a more efficient production process. The production process efficiency is manifested by different performance indexes—the level of output, reduced defect rate, improved product quality, and reduced lead time.

The production process is increasingly efficient because I40 technologies help reduce the lead time of operations and produce a high quantity of products compared to traditional production in all cases. In the I40 production process (Case A and B), these results rely on integrating various I40 technologies – robots and automatic sewing machine – which allows automating the entire production process. Still, the implementation of these technologies allows producing different shapes of products with different sizes and thickness. Thus, organizations exploit this feature making a novel gamut of products.

In the semi-automated line (Case D, E), the I40 technologies accomplish the first stage of assembly, which resulted in more repetitive tasks and where human errors occur, increasing the output of production. In Case D, a mechanical arm automates the first part of the prosthesis. In line with this, in Case E, the employment of cobots automates the pre-assembly stage of the assembly of the electrical switch, which conducts these activities faster, doubling the production.

Moreover, in Case A and B, I40 adoption produces goods with superior quality, and this is possible because the technologies are more accurate in executing operations. While in Case C, the high-quality production and the efficiency of production are supported by the superior competencies of workers in crafting ceramics.

Together with the increasing efficiency of production, I40 adoption enables better circulation of information. In Case A and Case B, the improved circulation of information was instrumental in performance improvement. Data produced by I40 machinery can be continuously used to scrutinize process performance and spot improvement opportunities. Down the assembly line, I40 technologies are integrated, and organizations can better govern the production process. Still, I40 adoption integrates the production process with the logistics unit, which allows for better management of product handlings because the interconnection of technologies allows producing and move the finished goods avoiding downtime.

In Case C, D, E, the better information circulation is evident in the integration of technical and administrative data, which contributes to improving accuracy in handling customers' orders. The better information circulation also helps workers manage their work, as they can view their performance and the performance of the whole line in real-time and compare them to benchmarks or targets. Still, in Case C and D, this improvement allows the keeping of under control the costs of raw materials – chalk and leather – which are employed in the production because the traceability systems gather information of the raw material used, its quantity wasted and utilized for finished products. This feature also helps to maintain active and constant production because the tracking system allows reducing the downtime in looking for the components bills or production sheets. While in Case E, the better circulation of information integrates the coordination among units, particularly between the production and the maintenance unit, which shows a reduction of intervention time on average. In line with this, tablets containing AR application facilitates workers to maintenance activities. These technologies, in Case E, contributes to maintaining active the workflow.

Furthermore, the adoption of I40 technologies allows the enhancement of the logistics unit performance in Case A, B, E. Automated forklifts conduct handling of products, which decreased all the accidental impacts which may break the carried products by maintaining a constant speed and employing sensors. In Case B, the automated warehouse also manages the products stored by sensors independently, which allows the better management of availability quantity.

Concerning the environmental dimension of the triple bottom line of sustainability, the leading-edge I40 technologies deliver an efficient production process that made the operations in the realizations of products more accurate with the employment of less raw materials. In Case A, B, D, E, the reduction of waste and the number of defective products is a consequence of introducing automated machinery that can perform demanding tasks more efficiently. The automation of logistics contributes to reducing production waste. In Case A, the management automated part of the logistics operations conducted by the forklifts where the inconstant speed was a precursor of the creation of faulty products, which they cannot often be reprocessed. In line with this, Case B automated the logistics operations in the warehouse, which reduces the possible collisions and, therefore, faulty products. The automation of the first stage of production in Case D and E avoids human mistakes due to the repetitiveness of tasks and optimizes raw materials' usage. In contract, In Case C, the reduction of production waste is the consequence of the use of digital technologies that guide workers on the operations they have to perform to reduce production mistakes.

I40 adoption also contributes to decreasing energy usage along the production line in Case A and E. The reduction of production issues by I40 automation, in Case A, prevents the extra energy cost, which is necessary to repair damaged goods - the secondary phase of the process. And the reprocessing of the product in the high-temperature oven, which is energy-consuming.

In Case E, smart sensors contribute to reducing the energy cost because they collect data of the assembly line, which are analysed to prevent common mechanical issues on cylinders of the conveyor. Thus, the maintenance unit can plan extraordinary maintenance to fix these potential mechanical issues. Also, maintenance activities are more rapid and help reduce energy waste because machinery can be stopped promptly.

Furthermore, I40 technologies contribute to reducing paper usage by digitalizing documents – bills of components and production sheets – along the assembly line in Case B. Also, the employment of a traceability system digitalizes the instruction documents of assembly products (Case B, C, D). The AR application even digitalizes the maintenance instructions of technologies (Case E).

Concerning the social dimension of the triple bottom line of sustainability, the primary outcome of adopting I40 technologies for all case companies is better work conditions for production workers. In Cases A, B, D, and E, the automation by robots mitigates the number of labour-intensive tasks for workers and decreases the likelihood of workplace accidents or becoming ill (e.g. as a result of inhaling fine particles of powder or microplastics). In Case C, the tracking system helps workers keep pace and visualize their performance in real-time and reduces the stress of potential disputes with management regarding performance level.

The workers also gain improved digital competencies and new skills for dealing with I40 technologies during the adoption process thanks to vocational training, mentorship, and training on-the-job. Workers can start and stop these technologies, and in Case E, assembly line workers address simple mechanical issues with AR application support. Refresher courses are also provided periodically. Thus, companies can then defend the workers' positions, as many workers who possessed only artisan skills in the traditional production process remained in the company as operators.

In Case A, B, C, and D, which are small-medium organizations, new positions entered the organization to exploit I40 technologies fully. However, these positions appear to replace or transform existing ones due to the profound difference in competencies between traditional manufacturing and I40. The new positions are knowledge-intensive jobs that exploit the information of I40 digital assembly lines to run either R&D activities or continuous improvement activities. In Case A and D, organizations hired new employees for the R&D laboratory and the digital administration because workers do not possess the specific competencies for those roles, and it was not possible to requalify them. While in Case B and C, the management maintained and requalified the current workers and hired new staff.

In contrast, in Case E, a large organization, I40 adoption does not require new positions within the organization. Yet, it requires that the workforce acquires novel competencies for additional activities that are currently in charge. This is the case of assembly line workers, which also conducts maintenance activities on I40 technologies and maintenance workers that also develops technologies. They program cobots, and they support the development of the AR application.

The social dimension differs the most across the cases, as we found some outcomes only in some specific cases. The case analysis revealed various forms of empowerment of the assembly line workforce that depend on the production process characteristics and are therefore not consistent across the cases. In Case A, B, D, E, the production process is automated by robots, which require supervision. Thus, the form of empowerment regards the shift from operational to supervision roles of assembly line workers. Also, in Case A and B, workers experienced more responsibility because they can suggest how to change the pace or other aspects of the production process.

In Case C and E, the production process remains manual. And it needs workers with proficient knowledge in crafting products. The traceability system supports this requirement because it allows monitoring workforce assembly time and providing vocational training to workers performing below standard. Still, I also found that workers increased control over the tasks they perform. They can self-organize to help each other in teams or on the assembly line and make decisions on the content of the tasks needing to be performed, suggesting improvements and solving problems along the line.

6.2 Industry 4.0 enablers for organizational sustainability

The analysis results show that the I40 adoption allows the organizations to support the entire triple bottom line of sustainability thanks to three enablers, which are summarized in Table 24. Two I40 enablers are consistent in all cases. They are the automation of the production process and the provision of timely and accurate information.

The automation of operations along the line allows improving production efficiency by increasing the output and quality of products. These outcomes provide the organization with a premium price on the market, with which they contrast competitors producing low-budget products. Thus, I40 adoption avoids the delocalization of production in countries where the workforce has low wages. Still, the increasing profit of the organization (showed by the balance sheets) increases the tax paid by organizations. Particularly in Italy, where the taxation is progressive, and therefore, the more organizations gain, the more taxes they pay. At the same time, the I40 automation of the production process is also beneficial for the environmental dimension because it safeguards the environment with a cleaner production. I40 technologies are more precise and use less raw materials, and they also reduce production issues that create production wastes.

			Sustainability Dimensions		
Case(s)	**Industry 4.0 Enabler**	**Action(s)**	**Economic Dimension**	**Environmental Dimension**	**Social Dimension**
All	Automation of the production process	Automatic assembly line Automatic logistic operations Manual and stress tasks to I40 technologies	Increased output quantity Increased product quality Reduction of time for time-to-market Reduction of damaged products	Reduction in usage of raw materials Reduction of waste	More valuable job position Reduction of work accidents Safer Workplace
All	Provision of timely and accurate information	Integrating information flow across units Digitalizing documents		Reduction of paper usage	Novel workforce role Novel units (In Case A, B, C, D)
A, B, D, E	Supervision of Workers	Checking production activities of technology Knowledge-intensive task More responsibility for workers Workforce as an innovator (In Case A, B, E)	A more constant workflow		Workers with novel digital competencies

Table 24 Industry 4.0 drivers support triple bottom line dimension

Moreover, the more efficient production process increases worker satisfaction because they consider their novel roles, based on knowledge-intense tasks, more valuable than the previous role job, based on manual activities. Also, workers experienced a safer workplace and reduced labour-intensive activities and work accidents because I40 technologies take on hand and repetitive tasks.

The analysis results also highlight that the adoption of various logistics technologies – programmed forklifts and automated warehouse – allows automating logistics operations, during which workers caused various damage to the product and reduced waste of productions. Their automated processes allow reducing the time for order fulfilment. Thus, organizations reduce time-to-marker, and customers can receive products in less time. Moreover, the number of products damaged during logistics operations decreased after the I40 adoption; thus, organizations reduced the waste of products, which often cannot be reprocessed. At the same time, workers experienced an enrichment of their role because they act as machine supervisors and no longer conduct labour-intense activities to move products or drive forklifts, which often are the cause of occupational illness.

Also, organisations reach a high-quality production process, which requires a continuous improvement of processes both for the automated and semi-automated assembly line. This is made possible by the role of workers who are part of a socio-technical system, which continuously supervises the production in order to maintain constant workflow. This outcome translates into economic value because the organization can produce the planned production quantity reducing issues that occur along the line. Still, in Case A, B, E, the workforce role reinforces these outcomes. They also act as an innovator, providing feedback to technology experts to optimize the automated production line and develop technologies for the assembly line. Such continuous commitment warrants continuous employment opportunities for workers in companies and sustains economic performance. Moreover, to conduct this supervision role, workers enriched their domain expertise with novel digital competences, which are developed and trained by vocational training, refresh courses, mentorship, and training on the job.

Organizations also enjoy timely and accurate information about the production process, retrieved by I40 technologies. Organizations exploit this I40 enabler in various ways. By interconnecting this information with administrative information, the organization digitalize various documents from the production sheet to the technology instructions that are no longer paper-based. Thus, organizations experienced a reduction in paper usage. Moreover, the growing amount of organizational data lays the foundation for novel roles within organizations. These novel roles are fulfilled by experienced workers who are requalified by vocational courses obtaining empowerment. Otherwise, organizations hired novel workers when it is impossible to requalify workers. It happened when organizations establish novel knowledge-based units, like the research centre or the novel IT unit.

6.3 Harmonizing the tensions of social and economic sustainability

Figure 7 summarises how the management of the cases address the tensions between the social and economic dimensions generated by I40 technologies. The analysis results show two sustainability tensions of I40 adoption that are consistent across all the cases: the reduction of human activities and the lack of digital competencies to manage I40 technologies. And one particular to just some cases, namely the reduction of production knowledge. Also, the analysis results highlight all the actions that management employs to address these tensions are mainly consistent across cases.

The first sustainability tension is the reduction of human activities due to the increasing automation of I40 adoption, which performs better production and logistics tasks. This concern is consistent in all cases that completely automate the assembly line (Case A and E) and in a semi-automated line (Case C, D, and E). In the automated line, workers see reducing production activities along the line, which they previously performed manually. The workers no longer move the goods and conduct operations on the production of them. While in the semi-automated line, workers decrease the production line activities in Case D and E. Also, in Case E, logistic workers no longer drive automated forklifts, and maintenance units no longer perform simple maintenance activities. While in Case C, workers no longer conduct support activities – the filling works – to manage the production.

Social Sustainability Concerns		Organizational Response to social sustainability concerns of I40 adoption
Case(s)	**Concerns**	**Actions**
All	Reduction of human activities	Increasing duties for the workforce of the assembly line
		Increasing duties for the maintenance of the assembly line
		Workforce performs novel creative activities
		I40 technologies automate only repetitive activities
		I40 technologies automate only labour-intensive activities
		Increasing task autonomy for workers
		New Organizational Units
All	Lack of competencies to manage I40 technologies	Vocational training for the workforce
		Training-on-the-job for workforce
		Mentorship for workforce
		Easy-to-use I40 technologies
		Courses of "The Academy"
A, E	Reduction of knowledge of the production process	Easier production activities
		Interchanging workforce between traditional and I40 assembly line
		Workers perform cobots activities when cobots are offline
		Fast job rotation for workforce along the assembly line
		Teamwork facilitates knowledge build-up
		I40 technologies support actions to increase knowledge of the production process

Figure 7 Managing the tensions between the social and economic dimensions of Industry 4.0 adoption

The management addresses the potential conflict between the social and economic dimensions involving the workforce since the beginning of the I40 innovation and increasing their duties. Several workers have seen their tasks enriched. Along the automated assembly line, the worker role shifts from a traditional manufacturing worker with manual tasks to an operator, which supervises the technologies and provides feedback to improve the technology operations. While in the semi-automated line, workers continue to perform manual activities and oversee technologies, blocking and restarting them to maintain constant the production process. Also, in Case E, assembly line workers experienced an enrichment of their tasks. They are in charge of simple maintenance activities thanks to the synergy between workforce and AR application, quality control and assurance activities on the work of their colleagues. Plus, in Case E, the maintenance workers are in charge of scouting new I40 technologies and supporting the development of those in use. While in Case A, B and E, the logistics workers programme and manage the automated forklifts rather than driving them.

Workers of semi-automated lines (Case C, D, and E) have increased autonomy. They can manage the activities they perform, helping each other's – especially to speed up underperforming lines – and to make these decisions, they are supported by screens showing the daily production trend in comparison with the target set for the day. The lack of these competencies may push the management of the reduction of the hired personnel.

Moreover, the transition of an I40 assembly required the settling of novel units to fully exploit the technologies in Case A, B, C, and D, which implies creating a new job role. Thus, the management has requalified staff of the traditional production line for the new roles when traditional workers can conduct them in Case B and D or have hired new staff in Case A and C[5].

The second sustainability tension concerns the lack of digital competencies for working with I40 technologies expressed by workers. I40 technologies are controlled by software, and workers need to be capable of using them.

The management addressed this problem by developing a lifelong learning path for the assembly line workforce. During the I40 adoption, workers attended vocational courses to learn how to use I40 technologies. During operations, each worker goes through a period of training on the job and can count on mentorship from skilled workers if the former feels she remains unfamiliar with I40 technologies. Periodically al workers receive training on the latest updates of the I40 technologies.

Still, in Case C, the management provides an "Academy" for novel workers and experienced workers who require learning how to work in the I40 line. These courses are more intensive than the training courses of the other organizations and have a final exam, and workers who attend and pass the exams receive a certificate.

The last sustainability tension, which is particular to Case A and E, is the reduction of knowledge of the production process by workers. In Case A, workers no longer conduct production activities, and this implies that experience workers and apprentices cannot train and maintain their know-how related to the crafting of ceramics. Therefore, they may lose their knowledge and skills of artisanal production that distinguishes the organization. In Case E, the workforce expressed concern regarding knowledge reduction on how to assemble the entire product. Also, how EVERYONIC trains workers to conduct the assembly activities privileges the human production steps neglecting the assembly phase performed by cobots. Workers also had difficulties addressing assembly issues of finished products or when faulty products come back to the firm.

The management of both organizations addressed this tension by interchanging workers between the traditional line and the novel I40 production line, which remained in place for small lots of

[5] The social dimension of the triple bottom line is addressed when an organization maintain unchanged or increase its staff number without considering whether workers are maintained after a technology adoption or are changed by new ones (Elkington, 1997; Hartmann, 2020)

productions and after-sale assistance. In Case A, workers are shifted to the I40 line when they have proper knowledge of ceramics, acquired during a period in the traditional line, which allows the worker to understand whether the technology conducts production activities effectively. In Case E, the work on the manual line helps workers increase their knowledge on the assembly of the entire switch because a single worker is in charge of assembling the product totally and fixing faulty products from the after-sale service.

Furthermore, the management of Case E realized further actions to maintain a higher knowledge production. Workers are frequently rotated down the I40 assembly line. Thus, workers perform various assembly activities, increasing the level of knowledge of the production phases and reducing the repetitiveness of assembly activities. Moreover, cobots need human support for loading and unloading operations, and the workers themselves manage the cobots. Thus, when cobots have difficulties in assembling components (due to different shapes or weights of switch components), the workers perform the task in place of the cobot.

Furthermore, the I40 assembly line strengthened the teamwork among workers: they now assist each other to improve their knowledge of the production process. Since each worker acts as a quality controller against the work of her colleague, the workforce develops analytical skills to potentially fix faulty assembly activities and helping co-workers to perform the activities better.

The work on the I40 assembly line is more straightforward than before because workers conduct microphases of the productions, allowing fast integration of apprentice workers, which experienced fewer issues to acquire the proper knowledge to work along the line.

Finally, the data analytics systems contribute to maintaining alive the knowledge of productions. The systems deliver reports with which managers identify workers regularly performing below standards. Management can provide to those workers countermeasures to improve the performance, including the possibility of attending tailor-made vocational courses, training, or discussing the pace of the work on the process. In line with this, a maintenance worker can verify whether upkeep is successful along the assembly line through the data analysis of smart sensors.

7 Discussion

This section discusses the multiple case study results against the related literature and answers the research sub-questions. In the first subsection, I discuss the sustainable value creation of I40 on the three dimensions of the triple bottom line. In the second subsection, I debate how the I40 enablers support the three dimensions of the triple bottom line. In the third sub-question, I clarify how organizations can address the tensions between the social and economic dimensions of the triple bottom line. For each sub-question, I state a theoretical proposition (Yin, 2018). I continue debating implications for researchers and future avenues of research. The chapter concludes with the presentation of implications for practitioners of the study.

7.1 Research Sub-Question 1: Sustainable Value Creation of Industry 4.0 adoption

The research sub-question one of the study is: *"What is the sustainable value that Industry 4.0 adoption delivers on three dimensions of the triple bottom line simultaneously in manufacturing organizations"?*

The sub-question is motivated by a lack of studies in the literature that show the sustainable value of three dimensions of the triple bottom line consequent to an I40 adoption. The multiple case study analysis fills this gap, illustrating that I40 technologies can be adopted to support all the dimensions of sustainability holistically. Therefore, these technologies deliver sustainable value on the three dimensions of the triple bottom line simultaneously for manufacturing organizations.

I40 adoption supports economic sustainability by optimising the production process and automating various operations along the line, resulting in high product quality and higher output quantity. Thus, the organizations can serve the market desirably and can sell their products better at a premium price. Moreover, the interconnection of I40 technologies allows improving the circulation of information by integrating technical and administrative data that is the vehicle of performance improvement, as data produced by I40 machinery can be continuously analysed to scrutinize process performance and spot improvement opportunities.

I40 adoption supports the environmental dimension, reducing natural resources usage thanks to more accurate technologies that conduct production operations with less raw materials and decrease the production waste. The logistics unit automation also reduces accidentally hurts, reducing the number of faulty products and all the costs to reprocessing (or throwing away) them. By analyzing data retrieved from I40 technologies, workers can promptly address mechanical issues of technologies reducing energy waste. I40 technologies also reduced paper digitalizing documents needed to manage the production and various instructions to assemble products and repair machinery.

I40 adoption also supports the social dimension positively. Workers enjoyed better work conditions because the labour-intensive or repetitive activities are taken on I40 technologies while they are in charge of supervision activities. I40 adoption helps workers effectively conduct their activities and improve their expertise because I40 technologies provide visual aid or intercept their errors, which are then corrected by tailor-made vocational courses. The workforce also acquired digital competence to work in the novel I40 production process and more autonomy in conducting tasks. Moreover, novel technologies require the establishment of novel knowledge-intensive units needed the requalification or the hiring of additional staff. This evidence contributes to maintaining a positive trend of workers that have increased in all the organizations afterwards the adoption of I40 machinery.

Discussing economic sustainability

Regarding the economic dimension, the study results are in line with the current literature. The study confirms that these technologies create value with efficient production and data circulation, which results in higher quality products on which a premium price is applied. The study illustrates various forms of improvements, which are little explored in literature. Particularly, the integration of technical and administrative data creates value for the organization by providing a better service for customers by the monitors of the production status. This is an example of vertical integration by I40 technologies, which extend the current literature because it illustrates the interconnection of various organizational units.

In contrast, the literature revealed mainly studies that aim at integrating multiple technologies along the line and in a single organizational unit (Kang et al., 2016; Shahbaz et al., 2012). Moreover, the study presents how the adoption of I40 technologies for the logistics unit and the exploitation of its data allows optimizing the operations of handling productions and storing them. This evidence advances the study of I40 technologies for logistics, mainly focused on the development of the IoT system and studying how to exploit data from smart sensors (Ben-Daya et al., 2017).

Discussing environmental sustainability

The study contributes to the literature related to the environmental dimension showing how I40 adoption reduces the usage of raw materials, energy, and paper. The study extents the relevant literature that mainly focuses on the environmental impact of peculiar technology (Zawadzki & Zywicki, 2016; Y. Zhang et al., 2018). The study illustrates the positive impact of I40 technologies on the environmental dimension that is significant when different I40 technologies are integrated. Indeed, conjointly using these technologies mitigates various ecological challenges of the organizations by automating demanding tasks and digitalizing administrative documents. Moreover, I highlight the worker role, which supports this dimension because they conduct ordinary maintenance on I40 technologies. They supervise the production and may address possible mechanical issues by analysing I40 technologies to avoid energy waste.

Discussing social sustainability

Concerning the social dimensions, the study contributes to the literature highlighting the various improvements that I40 adoption has on the workforce. The main study contribution mainly relies on presenting various social improvements. This extends the current literature, which considers the number of employees before and after the I40 adoption as the primary index to measure the social dimension (Hartmann, 2020). I started presenting this index during the case description employing official balance sheets and data to state that the organizations maintained a stable number of employees after the I40 adoption. Therefore, by considering this index, this study supports the social dimension. I also show that the I40 adoption required the establishment of novel units and more knowledge base activities to exploit I40 data. And to address this necessity, management requalified their workforce, maintaining the experienced workers in the organizations. When it is not possible, or the technologies require more workers, they hired novel staff.

The study also shows that I40 adoption is a means to improve work conditions with a safer and stimulating work environment, where workers are free from labour-intensive tasks and repetitive staff easier (Erol et al., 2016; C. K. M. Lee et al., 2017; Shamim et al., 2016). The workers reduced work illness and workplace accidents. These two results can be used as quantitative indexes for social sustainability, thus reducing the literature lack of social sustainability index (Hartmann, 2020).

The study also highlights that assembly line workers acquired novel digital skills to conduct supervision activities to machinery. This I40 outcome is barely studied in the literature (Gabriel & Pessel, 2016; Sony & Naik, 2019b), and the study explains what digital competencies are required for the novel duties of workers. Therefore, this study lays the foundation to create a job description for I40 workers, which lacks in the literature (Bonekamp & Sure, 2015; Kagermann et al., 2013).

Moreover, the results confirm the literature that I40 workers has a marginal role in manual activities (Kagermann et al., 2013; Kang et al., 2016) and extend this body of knowledge, showing that workers reaming pivotal along the production line supervising technologies and conductions support activities, including the maintenance of the technology. This outcome reflects the managerial choice to develop an I40 adoption, where the workers are at the centre of the innovation.

Answering the research sub-question 1

Figure 8 graphically summarizes the study contribution to the literature on the sustainable value creation of I40 adoption. These findings extend the relevant literature of sustainable value creation of I40 adoption, which considers the adoption of these technologies as a means to support one dimension of the triple bottom line. The study results illustrate that an I40 adoption can create sustainable value on the three dimensions simultaneously.

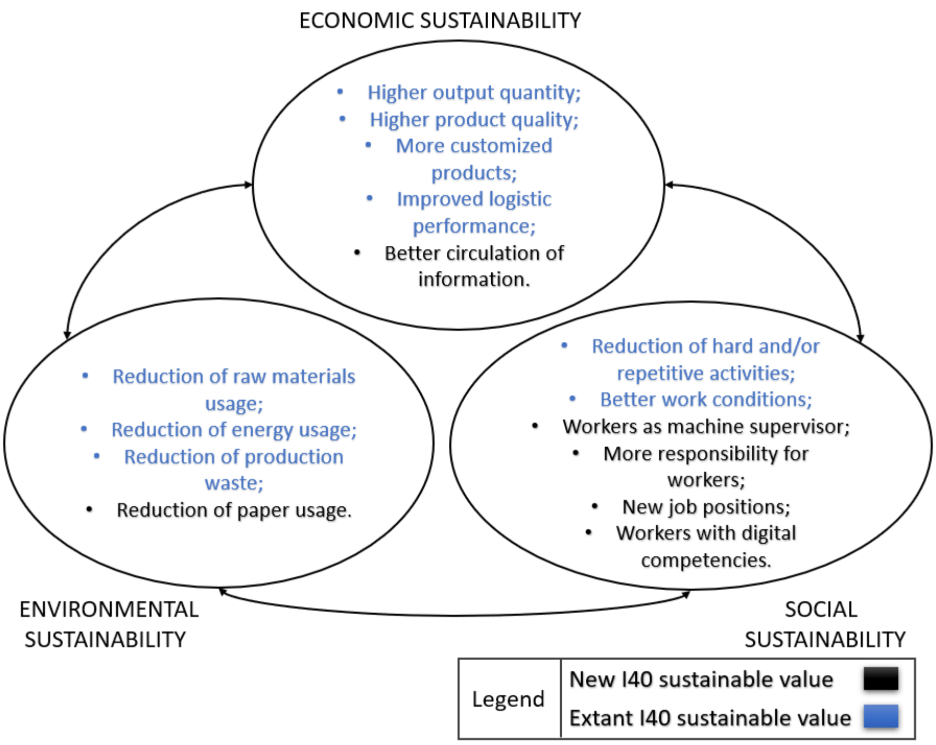

Figure 8 Contribution of the study to the sustainable value creation of industry 4.0 literature

Therefore, answering the research sub-question one, the proposition resulting from the investigation reads as follows.

Proposition. The I40 adoption delivers sustainable value on the three dimensions of the triple bottom simultaneously. The sustainable value of I40 adoption on the economic dimension is higher output quantity, higher product quality, more customized products, a more efficient logistic unit and better circulation of information. The sustainable value of I40 adoption on the environmental dimension is the reduction of usage of energy and natural resources as well as the reduction of the production waste. The sustainable value of I40 adoption on the social dimension is new job positions, worker's empowerment, better work conditions and novel digital competencies for workers.

7.2 Research Sub-Question 2: Exploring how Industry 4.0 adoption supports the triple bottom line

The research sub-question two of the study is: *"How does a manufacturing organization adopting Industry 4.0 support the three dimensions of the triple bottom line?"*

The research question is motivated by a lack of studies that explain how I40 adoption is an enabler of sustainability that support the three dimensions of the triple bottom line simultaneously (Beier et al., 2018; Kiron & Unruh, 2018; Machado et al., 2020). Indeed, the literature reports automation as an I40 enabler. However, following a technocentric perspective, this I40 enabler mainly supports economic sustainability, but not the entire triple bottom line (Kang et al., 2016).

The multiple case study analysis addresses this gap, illustrating I40 enablers that simultaneously support the triple bottom line. Figure 9 visually summarizes how I40 adoption supports the three dimensions of the triple bottom line.

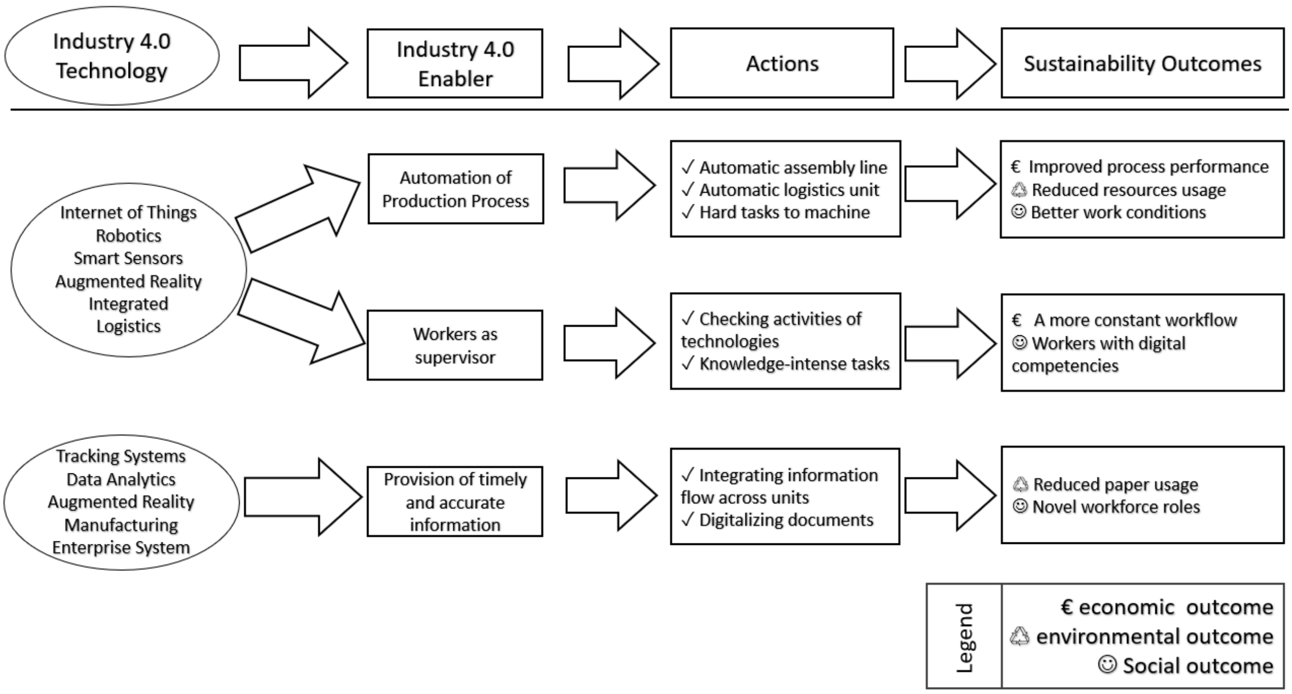

Figure 9 Industry 4.0 enablers supporting the three dimensions of the triple bottom line

I highlighted three process improvements: the enablers of I40 adoption for creating sustainable value. I40 enablers are in the form of increased automation of the production process using automated machinery for dangerous tasks, human supervision of machinery, and the provision of timely and accurate information. These enablers lead to sustainable organizational outcomes for all three dimensions of the triple bottom line: a more constant workflow and improved process performance (economic dimension), reduced resource usage (environmental dimension) and better work conditions, new job positions, more responsibility for workers and increased competencies for workers (social dimension).

A more constant workflow and an improved process performance - an efficient production process and logistics process and better circulation of information - translate into improved economic performance. Thus, companies can deliver a higher output of high-quality, defect-free, customized products to the market at a premium price. Also, organizations can sustain their competitive advantage based on high-quality products, and they can serve better the market fulfilling customer's need. The reduced resource usage promotes more sustainable products and services thanks to the reduced need for energy and the reduction of waste. Analogously, organizations stem from paper usage along the production process. While the better working conditions have a motivational effect in terms of workers' morale, the need to have skilled supervisors and the availability of timely and accurate information offer workers new opportunities to take on new roles and responsibilities, with several new knowledge-intensive positions appearing in organizations and new job roles on the assembly line.

Such opportunities contribute to social sustainability, as in this way, organizations implementing I40 technologies can defend employment levels. On one side, the number of workers required declines due to automation. On the other side, organizations can offer workers the right skills and knowledge jobs operating I40 machinery or positions related to planning, controlling and researching that the shift to I40 stimulates.

However, the outcomes on social sustainability can be considered detrimental for workers as well. More specifically, the analysis is grounded on organizations that wanted to maintain their extant workforce and spent economic resources to develop a learning path to requalify workers with manual competencies. Thus, the worker role as machine supervisor can have a beneficial effect both on the technical the social side of the production. However, organizations can exploit this job enrichment and the need to develop more digital competence for the workforce to reduce the organizational set-up. Organizations can fire extant workers and hire a novel workforce with proper competencies to work with I40 technologies avoiding costs related to the learning path. Or, organizations can directly delocalize their plants in countries with lower taxation and a lower cost of labour and hire a novel workforce in order to reduce organizational costs.

Therefore, these results are only possible when I40 technologies are deployed with a worker-centric approach to enhance the workforce capabilities and thus improve the production process. Contrarily to the technocentric perspective, which considers workers with a marginal role along the production line (Kang et al., 2016). They also have fewer opportunities for stable employment in a manufacturing organisation (Chin et al., 2019; Rafiq & Chin, 2019). The worker-centric approach underpins a socio-technical perspective of I40 technologies, where workers actively participate in the production process and collaborate with technologies to realise products. As such, the management considered the features of I40 technologies as a resource to improve the economic sustainability of the organizations. They avoid the mere adoption of technologies that competitors could easily imitate because they leveraged workers' activities, including supervision, experimentation and feedback, to improve the production process. Thus, organizations are encouraged to maintain a skilled workforce that can deal with I40 technologies.

Thus, a socio-technical interplay occurs in an I40 production process. While I40 technologies operate production activities, workers supervise them to maintain the production constant and spot the possibility to improve the production process. To sustain this interplay, applying this worker-centric approach pushes organizations to automate all the dangerous tasks or in which workers might make more mistakes (resulting in an increased defect rate). The worker-centric approach has two consequences: the increased knowledge intensity and continuous retrofitting of I40 technologies. These consequences can further contribute to the sustainable value of I40 adoption. The need for workers proficient in managing digital I40 technologies and the availability of data produced by the technologies increase the relevance of the knowledge dimension of manufacturing as workers move from crafting activities to activities related to the utilisation of technology and related problem-solving. Within a knowledge-intensive organization, workers enjoy less alienating working conditions and a higher degree of job satisfaction (C. K. M. Lee et al., 2017).

The workforce composition has changed both in the I40 production process and within companies where several knowledge-intensive positions have appeared. The commitment to improve the production process has been pursued by workers who perform activities with a high level of knowledge (Erol et al., 2016; Shamim, Cang, Yu, & Li, 2017). And they act as primary drivers of continuous fine-tuning of the I40 production process and by units related to I40 technologies. The analysis showed that in the case of small-medium organizations, the adoption of I40 technologies is accompanied by the establishment of R&D units, production control units, or administrative units, all exploiting the information produced by the I40 machinery.

Another aspect of the social sustainability of I40 technologies is the increase in employment levels because of companies' success in the market (like in Case B). This requires companies to employ more workers to increase output levels. However, it is relevant to point out that such an increase requires a profound transformation of the workforce. They need to learn new skills through a lifelong learning path composed of vocational training, mentoring, training-on-the-job, and refresh courses. The number of employees is defended or increased, but they are not the same employees as before. Only in two cases, the organization succeeds in maintaining both the old and the new production processes. In this way, they could keep workers with manual assembly competencies. However, further research is needed to prove generalizability.

From a process perspective, I40 technologies have to incorporate these improvements to optimize production process automation. For instance, whether technology experts change the I40 production process algorithm, I40 technologies afford the production process to receive and apply these new movements. Likewise, in case of the development of a new mixture or utensils for the production process, I40 technologies afford to harmonize movements and afford to handle them accordingly. To describe this feature, we employ the term *adaptive* to refer to technology possibility to implement these process improvements to optimize automation easily. The cases showed that this feature is applied in different ways. It applied in the production processes to improve the underfit of the process —in essence, the change of materials and material flows in the process (Cases A and B) —, the change of the sequence of operations on the same machine (Case B, D, and E) and the change of workers' activities based on monitoring information (Case C). Hence, within the I40 context, continuous retrofit of the process does not necessarily lead to the disappearance of jobs, as happened with mass-scale automation (Bonekamp & Sure, 2015; Frey & Osborne, 2017; Nurazwa et al., 2019; Tangmunarunkit et al., 2015).

Moreover, the analysis shows the importance of management in choosing and undertaking a worker-centric approach in adopting I40 technologies. The top management has a strong commitment to sustainable innovation for the workforce. Management sets a clear strategy for the introduction of I40 technologies and includes a vision that explains what I40 adoption intended to achieve. Management deploys I40 technologies to improve productivity, reduce natural resource usage and defend jobs. The study shows that management is receptive to innovation, which is designed to support workforce activities. To this end, the study shows that workers are involved in the planning of the innovation. The management discussed the innovation with workers and acquired feedbacks to choose an innovation suitable for the organizations and workers. The same feedback is translated in technical instructions for technology developer to design proper I40 technologies which improve the production process and work conditions. Management also prepares the workforce for innovation, explaining how the production process will change, avoiding resistance to the change. Therefore, top management support is not only seen as a resource allocator but also as someone who supports the change in organizational structures, planning, organizing, and directing. Top management continues its strong commitment to supporting innovation during the adoption stage. Indeed, being the organizations the first adopters of I40 technologies in its sectors, the management decided to take on the risk of the I40 adoption and develop a new production process compatible and coherent with the traditional way of producing products. During the production process, the management supports the technology developers to integrate the technologies along the line and support developing a path to build workers capable of dealing with I40 technologies by vocational courses.

Therefore, answering the research sub-question two, the proposition resulting from the investigation reads as follows.

Proposition. The adoption of I40 technologies supports the three dimensions of the triple bottom line when deployed with a worker-centric approach and with continuous retrofitting of I40 technologies. This approach pushes the transition to knowledge-intensive companies where workers remain in a pivotal role within the organization. The core activities of workers shifted from manual tasks to activities related to the use of technology and associated problem-solving. This transition requires a number of knowledge-intensive positions. The management involves the workforce during the planning and the adoption of I40 technologies. Thus, they set clear goals to achieve with I40 technologies in order to sustain the economic and environmental, and social dimension. The workforce benefits from less alienating working conditions and a higher degree of job satisfaction (social dimension), while the organization experience more efficient (economic dimension) and cleaner production (environmental dimension). I40 technologies should be designed to be continuously retrofitted for receiving and implementing improvements; thus, workforce activities can improve the production process.

7.3 Research sub-question 3: Discussing how organizations address social and economic sustainability tensions

The research sub-question three is: *"How does a manufacturing organization employ Industry 4.0 technologies to address the tensions between social and economic sustainability?*

The current literature of sustainable value creation of I40 adoption illustrates a tension between social and economic dimensions of sustainability due to the increasing automation that I40 technologies deliver. Even though this feature can improve the production process enabling a more efficient production, at the same time the automation can replace workers with technologies to seek and increasing productivity and profitability (Hooker & Kim, 2019; Kang et al., 2016; Wright & Schultz, 2018). This consequence implies that I40 adoption cannot support the three dimensions of the triple bottom line simultaneously because the fulfilment of the economic dimensions is the dissatisfaction of the social one.

The study results confirm the importance of I40 automation, which appears as an I40 enabler supporting the triple bottom line dimensions. Nevertheless, the study also highlights three chiefly sustainability tensions during the I40 adoption: the reduction of human activities, the lack of competencies to manage I40 technologies, and the reduction of workers' knowledge of the production process. The management addressed these tensions following a worker-centric approach, which allows for a viable balance between automation and human labour.

The literature of I40 reports that assembly tasks are easy to automate because they are repetitive (Frey & Osborne, 2017), and this automation causes job disruption for low skilled workers (Bonekamp & Sure, 2015; Kang et al., 2016).

The study shows that I40 adoption allows automating labour-intensive and/or repetitive activities of the workforce, avoiding human intervention in these steps. Nevertheless, the management in the cases used a portfolio of solutions – vocational training, training on the job, and mentoring – to upskill the workforce and let them learn the novel duties which, eventually, are more abundant in creativity and autonomy (Erol et al., 2016; Shamim et al., 2016). The I40 workforce duties are enriched with supervision, maintenance, configuring, monitoring, and continuously improving the I40 technologies. Moreover, novel internal units are established, which require workers with novel duties related to the analysis and the exploitation of data from I40 technologies. Also, the potential loss of tasks is compensated by improved work conditions since workplaces are more ergonomic, healthier, and tasks to perform are easier (Erol et al., 2016; C. K. M. Lee et al., 2017; Shamim et al., 2016).

I40 assembly lines require a skilled workforce that understands how to work with I40 technologies (Kagermann et al., 2013; Sony & Naik, 2019b). This requirement forces traditional manufacturing organizations to replace experienced workers with a more specialised workforce with a potential loss of know-how and expertise on the organisational production activities or to reskill them (Bonekamp & Sure, 2015; Nurazwa et al., 2019). The workforce requalification in I40 is challenging since the differences between traditional manufacturing workforce competencies, and I40 digital competences are large (Chin et al., 2019).

The study shows that this aspect is managed in two way. Firstly, organizations provide lifelong learning paths for the workforce through vocational courses, mentorship, training on the job during the adoption phase and periodical refresher courses. Secondly, organizations simplify worker tasks with I40 technologies. I40 technologies employ intuitive software that facilitates the management of production operations. Also, I40 technologies, particularly the AR application and tracking system, step-by-step guide workers on assembly or maintenance activities, supporting their growth of expertise while enlarging their duties on the assembly line. Thus, the development of a poly-specialistic workforce allows optimal performance of production activities and support activities to the line which concerns the management of I40 technologies.

Furthermore, the literature portrays that automation of workforce core activities reduces knowledge of the workforce on production activities as workers cannot practice these tasks daily (Bonekamp & Sure, 2015; Nurazwa et al., 2019). This circumstance may lead to a low performance along the production process by the workforce. The study allows arguing that the same implication happens in semi-automated line, where repetitive activities are automated along the production process. Also, this tension is addressing differently according to the way the line is automated.

In a fully automated line, where each worker supervises a single production, the management builds the production knowledge assigning workers to the traditional production line. They acquired this knowledge by conducting production activities. Thus, apprentice workers are first employed in the traditional line, whereas experience workers are used in the I40 line after acquiring proper competencies to work with technologies.

While down the semi-automated line, the workforce cooperates with cobots. They way I40 technologies reshape the production process into several phases makes workers experience a hyper-specialisation for those phases they conduct. Moreover, workers experience a lack of knowledge to assembly the entire product, fix finished products and for the activities performed by I40 technologies. Thus, the management addressed these issues by assigning the workforce the task of managing I40 technologies, taking their tasks when they are offline, and interchanging the workforce between the traditional and I40 assembly lines. Also, the task easiness, peer supervision, and the rotation of workers across phases and lines stimulated the growth of group dynamics that support performance and knowledge sharing.

Therefore, the study shows how organizations exploit I40 technologies to automate the production process and support workforce empowerment through job rotation, job enrichment, and upskilling. The workers lose relevance on a large part of the production activities. Their tasks on the assembly line are entirely automated or fragmented, but they take on more duties. In the cases, assembly line workers work both as supervisors, fine-tuner of technologies and quality controller.

The interplay between the workforce and I40 technologies allows continuous optimization of the production process and increases workforce capabilities. The transition toward I40 adoption also increases the workforce competencies related to the management of I40 technologies by vocational training and their knowledge of the production process. Moreover, I40 technologies sustain this competence growth of workforce and performance at the same time. The measurement of time for each production phase and the mentoring and the training-on-the job ensures both managerial visibility on individual and overall performance, the continuous improvement of workers performance who are also in the condition to help each other and learn from each other's experience. Under this perspective, technological progress supports economic sustainability increasing production efficiency and social sustainability, reinforcing at the same time the role of workers.

Therefore, answering the research sub-question three, the proposition resulting from the investigation reads as follows.

Proposition. I40 technologies deployed with a worker-centric approach allow automating production activities along the assembly line and supporting workforce empowerment through reduced routine work, enlarged and enriched duties. The automated production activities require human supervision to maintain constant production and operate effectively in case of technical issues. Thus, the workforce takes on supervision, fine-tuning, and continuous optimization activities on the assembly line. In doing so, the workforce requires more competencies to work with I40 technologies and a higher level of knowledge of the production activities.

7.4 Implications for researchers & future avenues of research

The study has certain implications for researchers. Based on the multiple case study, I proposed three theoretical propositions for an I40 adoption that generate sustainable value supporting the triple bottom line dimensions holistically, which I report in Table 25. I believe that these propositions can contribute to the genesis of a research agenda for future studies in the field. Therefore, I encouraged researchers to develop these propositions further by adopting a number of methodological angles, such as qualitative – especially action research and Fs/CQA analysis – and quantitative approaches.

Questions	**Propositions**
What is the sustainable value that Industry 4.0 adoption delivers on three dimensions of the triple bottom line simultaneously in manufacturing organizations?	The I40 adoption delivers sustainable value on the three dimensions of the triple bottom simultaneously. The sustainable value of I40 adoption on the economic dimension is higher output quantity, higher product quality, more customized products, a more efficient logistic unit and better circulation of information. The sustainable value of I40 adoption on the environmental dimension is the reduction of usage of energy and natural resources as well as the reduction of the production waste. The sustainable value of I40 adoption on the social dimension is new job positions, worker's empowerment, better work conditions and novel digital competencies for workers.
How does a manufacturing organization adopting Industry 4.0 support the three dimensions of the triple bottom line?	The adoption of I40 technologies supports the three dimensions of the triple bottom line when deployed with a worker-centric approach and with continuous retrofitting of I40 technologies. This approach pushes the transition to knowledge-intensive companies where workers remain in a pivotal role within the organization. The core activities of workers shifted from manual tasks to activities related to the use of technology and associated problem-solving. This transition requires a number of knowledge-intensive positions. The management involves the workforce during the planning and the adoption of I40 technologies. Thus, they set clear goals to achieve with I40 technologies in order to sustain the economic and environmental, and social dimension. The workforce benefits from less alienating working conditions and a higher degree of job satisfaction (social dimension), while the organization experience more efficient (economic dimension) and cleaner production (environmental dimension). I40 technologies should be designed to be continuously retrofitted for receiving and implementing improvements; thus, workforce activities can improve the production process.
How does a manufacturing organization employ Industry 4.0 technologies to address the tensions between social and economic sustainability?	I40 technologies deployed with a worker-centric approach allow automating production activities along the assembly line and supporting workforce empowerment through reduced routine work, enlarged and enriched duties. The automated production activities require human supervision to maintain constant production and operate effectively in case of technical issues. Thus, the workforce takes on supervision, fine-tuning, and continuous optimization activities on the assembly line. In doing so, the workforce requires more competencies to work with I40 technologies and a higher level of knowledge of the production activities.

Table 25 Theoretical Propositions of the study

Moreover, the results of the study revealed a more complex socio-technical system. In an I40 context, the socio-technical interplay between technologies and workers occurs during supervision activities.

While technologies conduct production activities, the workforce performs supervision activities to address potential machine issues and provide feedback to improve the process. Therefore, the study contradicts the statement that I40 technologies reduce employment levels (Bonekamp & Sure, 2015; Kang et al., 2016).

This socio-technical interplay is enabled along the production process when workers possess proper competencies and production knowledge to manage I40 technologies. At the same time, I40 technologies afford to conduct production activities and support to be reprogrammed by technology experts in order to incorporate changes in their activities – I call this feature *adaptive* – which are proposed by workers that use their knowledge and competence to improve the production process.

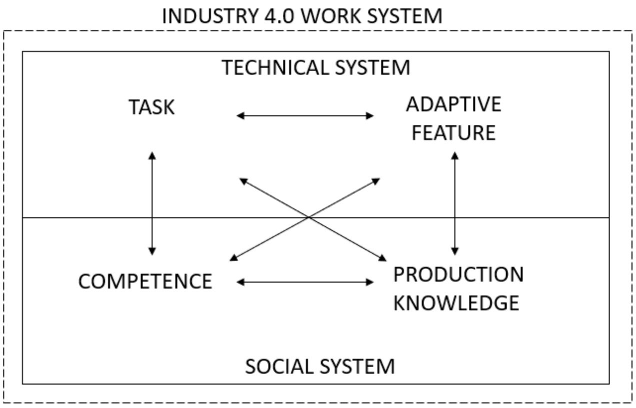

Figure 10 Socio-technical Framework for Industry 4.0 production process

Figure 10 graphically shows the socio-technical framework for the I40 production process. Each system embraces various components, which are the automated tasks and the adaptive feature of technologies for the technical system and the competence and production knowledge of workers for the social system. Further studies are needed to validate the framework and its components in vertical and horizontal adoption of I40 technologies because this framework is grounded in this study.

Workers require digital competencies to work with I40 technologies. This is a requisite for successful I40 adoption that the current manufacturing workers do not possess. Organizations address this concern by proposing a life long path for workers based on vocational and refresher courses. Further studies should advance this discourse investigating the proper competencies that workers possess to be ready for an I40 context by realising a competence framework listing these competencies. This study can also be notably useful for the Human Resource unit during the implementation stage, where it can be used as a required competence to seek in the labour market. It is also valuable for maintaining a high competence level in mature I40 organizations preventing competence lack through the competence gap analysis (Hecklau, Galeitzke, Flachs, & Kohl, 2016).

Another implication of the study is the crucial role of production activity knowledge of workers to manage and improve the production process as well as the rise of novel knowledge-intensive positions consequent to the introduction of I40 technologies. Future researchers should investigate how the knowledge management in I40 organizations can capture, distribute and help workers use knowledge (Davenport & Prusak, 1998). And how organizations deal with the transition of knowledge when there is significant turnover. This includes dimensions related to the use of the data produced by the I40 technological infrastructure to generate knowledge. I consider this is a significant avenue of future research, mainly because the next I40 technology that will impact the organization is artificial intelligence. Artificial intelligence may change the interplay between the workforce and I40 technologies, for example, by automating more substantial decision-making activities. Thus, artificial intelligence can potentially harm the sustainable social outcomes created by the I40 technologies we identified, with even more tasks moving from workers to machines. Accordingly, it can disrupt the novel knowledge-intensive roles created to manage I40 technologies and the associated data.

The study is also a call for information systems research, which often focuses on the impact of administrative systems and data, to study IS in production units and to investigate how data generated by I40 technologies on the assembly line can be integrated with the rest of the data organizations possess (Lasi et al., 2014). Future investigations should examine how and to what extent the I40 data retrieved from assembly lines are managed to create sustainable value for each dimension of sustainability. To this end, our study is a starting point because it describes several technologies—notably the tablet containing the tracking system and the AR application—to increase control of the workforce to deliver value. How does this data deliver additional value to organizations without raising concerns about privacy, surveillance and control of workers? In our study, we found forms of worker empowerment. However, they are not consistent across all the cases. Instead, in every case, workers are in a production environment where managers have a complete audit trail of their actions and performance.

The sustainable organizational value of I40 technologies devises further studies. This study contributes to the increasing body of knowledge concerning the social dimension value of I40 technologies. Further studies are needed to extend this dimension and validate the findings (Ghadimi et al., 2019; Kamble et al., 2018). Moreover, researchers should continue the investigation of the value on the environmental dimension of I40 technologies and particularly exploring the link between the I40 technologies and circular economy practice because the circular economy can mitigate the negative impact of manufacturing organizations on the planet (de Sousa Jabbour, Jabbour, Godinho Filho, & Roubaud, 2018).

The study has some limitations. Since it is based on five cases of organizations located in Italy, the results of the dissertation are mostly generalizable in organizations operating in the European context. That share similar characteristics – firm size, industry type, and level of governmental support to the adoption of these technologies – to the Italian context. The study results explain in detail the sustainable value creation of I40 adoption and can be used as a starting point to keep exploring the topic in various context. Therefore, I encourage researchers to validate my findings and investigate the sustainability of I40 adoption in other contexts and countries, including developing countries, Asian countries and North and South American countries.

Also, dissertation results illustrate qualitative benefits of the I40 adoption on the environmental sustainability – the reduction of energy usage, natural resources, and production waste – without using quantitative data that organisations do not have. Further studies should overcome this limitation by including in the analysis data related to the usage of natural resources and energy or environment indicators (such as carbon footprint), which allow comparing the consumption of natural resources and CO2 emissions of the organisation before, during and after the I40 adoption.

7.5 Implications for practitioners

Practitioners can use this work as a guideline for organizations aiming to adopt I40 technologies and reduce resistance to change by workers scared of losing their jobs. The study shows that I40 technologies deliver sustainable organizational value (Kiel et al., 2017; Margherita & Braccini, 2020d). It shows the potential benefits that organizations can expect from the adoption of these technologies. Thus, the fulfilment of the triple bottom line is an achievable goal, even in practice.

The results can also help practitioners address potential resistance to change by workers. Based on the case results, the workforce role in a worker-centric deployment of I40 technologies is pivotal for sustainable organizational value. Practitioners should clear strategy for the introduction of I40, and it includes a vision that explains what Industry 4.0 is intended to achieve. Management should set clear goals that are understandable and achievable (Julian M. Müller, 2019). Still, practitioners should manage the adoption process of I40 technologies with a participative approach involving the workers both during the planning and the adoption of the technologies. In this way, workers straightforward accept the technologies because they can understand how the production process will change and how they enjoy the novel production process.

To exploit the full potential of I40 adoption, the pieces of evidence of our case mandate organisations to develop a lifelong learning path to enrich workforce competencies on I40 technologies (Erol et al., 2016). Vocational training plays a crucial role in I40 adoption and shall be tailor-made to each worker employed in the assembly line. Training-on-the-job and mentorship conclude the workforce training straightening knowledge of production activities. Still, the study illustrates the importance of teamwork attitude, job rotations. Thus, workers maintain a high level of knowledge of the production operations. Practitioners should employ I40 technologies to automate repetitive and/or labour-intensive tasks, improve workforce conditions and empower the workforce with novel knowledge-intensive activities, including technology supervision with a higher degree of autonomy. The continuous improvement of the I40 production process is also possible through the continuous action of workers with the competencies to manage I40 technologies and provide feedback on the way they work. Thus, the transition to I40 production processes does not automatically imply a reduction in the employment level.

The results also show that organisations should implement I40 technologies gradually and singularly. The cases show that I40 technologies are integrated after their successful implementation. The results also show that technology experts help organizations choose the right technologies for their needs, support the implementation, and contributes positively to significant I40 adoption. Also, practitioners should orient their choice to eco-friendly technologies to reduce the impact on the environment.

In this period of recession due to the COVID-19, the deployment of I40 technologies with a worker-centric approach is a valid strategy for fighting the economic crisis allowing to increase the quality of products and production output while defending job positions for the community.

Moreover, the study is beneficial for policymakers that want to develop incentives to improve worker conditions and boost innovation in the manufacturing industry. So far, most industrial initiatives provided financial support to organisations to buy I40 technologies by reducing tax and favourable credit terms. By knowing how I40 technologies contribute to sustainable organizational value, policymakers may develop more organic incentives that do not aim at stimulating the acquisition of the technologies but instead promote the sustainable digital transformation of manufacturing. The study reports the sustainable value of I40 adoption that can be incorporated within industrial initiatives as a milestone to reach for organizations to receive further incentives.

The study is also useful for temp agencies that seek workers for manufacturing organization adopting I40 technologies. The study reports that workers to employ in an I40 context should have a profile rich in digital competencies to work with these technologies. Therefore, these agencies should select workers with these competencies or train them before starting the contract rather than selecting workers with manual expertise (Erol et al., 2016).

Finally, the study helps technology experts in designing I40 technologies to shift from a "technocentric" approach to a worker-centric approach where the workforce has a prominent role in the production process. To this end, technology experts should design I40 technologies that are intuitive and simple to interact with, and easy to use for workers (Margherita & Braccini, 2020a; Sony & Naik, 2020). By adopting this paradigm, the workforce performance in supervising technologies is effective, and organisations can flexibly recruit new workers and quickly train them when needed. Still, the study showed how the interplay between technology and people leads to sustainability value through increased production efficiency and 'humanizing' work (Sarker, Chatterjee, Xiao, & Elbanna, 2019) by addressing the three dimensions of sustainability.

8 Conclusion

I conduct a multiple case study to investigate how adopting I40 technologies in manufacturing organizations influences organizational sustainability. I assess sustainability by the three dimensions of the triple bottom line. The dissertation findings address the extant literature gap related to the link between I40 adoption and the three dimensions of the triple bottom line holistically. More specific, I40 adoption, by exploiting a high level of automation, supports satisfactory one dimension of the triple bottom line, particularly the economic and environmental dimensions, but not the three dimensions simultaneously. Moreover, the automation delivered by these technologies deserves further attention because this feature is at the foundation of the tension between the economic and social dimensions, which impedes an I40 adoption to fulfil the triple bottom line holistically.

The study has been guided by three sub-research questions that synthesized the research gaps: (1) What is the sustainable value that Industry 4.0 adoption delivers on three dimensions of the triple bottom line simultaneously in manufacturing organizations? (2) How does a manufacturing organization adopting Industry 4.0 support the three dimensions of the triple bottom line? (3) How does a manufacturing organization employ Industry 4.0 technologies to address the tensions between social and economic sustainability?

The I40 adoption delivers sustainable value on the three dimensions of the triple bottom simultaneously. The sustainable value of I40 adoption on the economic dimension regards higher output quantity, higher product quality, more customized products, a more efficient logistic unit and better circulation of information. The sustainable value of I40 adoption on the environmental dimension is the reduction of usage of energy and natural resources as well as the reduction of the production waste. The sustainable value of I40 adoption on the social dimension is new job positions, worker’s empowerment, better work conditions and novel digital competencies for workers.

The way in which I40 technologies deliver sustainable value on the three dimensions of the triple bottom line pushes the transition to knowledge-intensive companies, where workers remain in a central role within the organization, and the continuous retrofitting of I40 machinery. The core activities of workers shifted from manual tasks to activities related to technology utilization and associated problem-solving. This transition requires a number of knowledge-intensive positions. The workforce benefits from less alienating working conditions and a higher degree of job satisfaction. At the same time, organizations experience more efficient and cleaner production. To this end, top management involves the workforce during the planning and the adoption of I40 technologies. Thus, they set clear goals to achieve with I40 technologies in order to sustain the economic and environmental dimensions, while the workforce helps to set those goals to address the social dimension by detecting workforce issues. I40 technologies are designed to be continuously retrofitted for receiving and implementing improvements. Thus, workforce activities can improve the production process.

The automation of I40 technologies is used both to improve the production process and support workforce empowerment through reduced routine work, enlarged and enriched duties. The workforce takes on supervision, fine-tuning, and continuous optimization activities on the assembly line. In doing so, the workforce requires more competencies to work with I40 technologies and a higher level of knowledge of the production activities.

Therefore, the findings of my PhD dissertation illustrate various facets of the developed worker-centric approach, which stands against the "technocentric" vision of I40 technologies where the pieces of machinery are the main enabler to create organizational value. In contrast, the worker-centric approach to I40 adoption illustrates that the role of workers remains in a pivotal role within the organization. Their interplay with technologies contributes to the creations of sustainable value for organizations.

Since I had an interpretive posture for the research, the study results are mostly generalizable in organizations operating in the European context that share similar characteristics to the Italian context. This context is characterized by manufacturing organizations that receive funds from governments to buy I40 technologies and are also encouraged to reduce environmental impact. Another trait of the context is that these manufacturing organizations adopted these technologies to act sustainability and increase the quality and customization of products. Further studies are required to validate the finding. To this end, I proposed three theoretical propositions (summarized in Table 25) that can be statistically tested in future studies.

Finally, my findings are relevant for various groups of practitioners. Managers and I40 consultants can use the results of this work as a guideline for organizations aiming at sustainably adopt I40 technologies. I40 technologies need to be implemented gradually, singularly, and workers need to be involved during the planning and the adoption of these technologies in order to address their resistance to change. To prepare workers to deal with I40 technologies, organizations should develop life-long learning for workers in order to build digital competencies through vocational courses, training-on-the job and mentorship.

A temp agency can create an appropriate profile of workers operating in the I40 context that require more digital skills than manual skills. Technology experts should design technologies that allow workers to interact through intuitive, simple and easy to use software. The research also helps policymakers develop incentives to improve worker conditions and boost innovation in the manufacturing industry. The findings report the sustainable value of the three dimensions of the triple bottom line that can be incorporated within industrial initiatives as a milestone to reach for organizations to receive further incentives.

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Appendix

In this section, I illustrate the interview track for managers and workers in appendix A, the most significant excerpts by the dimensions of the analysis in appendix B, and the list of acronyms in appendix C.

Appendix A

Table 26 shows the interview track, which I used to interview the management and middle management of the organizations.

Topic	**Item**
Information about the organization	Tell me about your organizational story How many employees do you have in the organization? How many woman and man?
Information about the interviewee	What is your role within the organization? How many years have you been working here?
Industry 4.0 technologies	What Industry 4.0 technology did you adopt in the organizations? Where did you adopt Industry 4.0 technologies? In which organizational unit?
Adoption Process	Did you manage the Industry 4.0 projects? What was your role during the adoption process? Did you have problems with their adoption? How did you support the adoption process? Did you include the workforce in this process? How?
Traditional production Process	How was your production process before the Industry 4.0 technologies? What are the main problems you had in the line? How was the workforce role?
Industry 4.0 Production process	How does the production process change after the Industry 4.0 adoption? Did you change the production line?
Economic Value of Industry 4.0 adoption	What is the economic value of the Industry 4.0 technologies? Does the production line increase the output of production? Does production improve the quality of the products? Do you have other positive outcomes of these technologies?
Environmental sustainability of Industry 4.0 adoption	Do you consider the environmental impact of these technologies? Do Industry 4.0 technologies contribute to mitigating the environmental impact of the organisations?
Social sustainability of Industry 4.0 adoption	Does the organization increase employee numbers after the Industry 4.0 adoption? How was the impact of Industry 4.0 on the organizational structure? Does the organization increase employee numbers after the Industry 4.0 adoption? Does the role of the production line workers change after the adoption of Industry 4.0 technologies? Does the adoption of Industry 4.0 technologies improve workforce conditions?

Topic	Item
Concerns of Industry 4.0 automation	How do you manage the negative automation of Industry 4.0 technologies? Do you use automation to improve workforce condition?

Table 26 Interview track for managers

Table 27 shows the interview track, which I employed to interview both workers and their supervisors.

Topic	Item
Role of worker	• Tell me about your work. What tasks do you conduct? • What are the benefits of Industry 4.0 adoption on the workforce? • How do your work conditions change after the Industry 4.0 adoption? • Do you consider that the automation of Industry 4.0 facilitates your work? Why and how? • What is the economic value of the Industry 4.0 technologies? • How do Industry 4.0 technologies mitigate the environmental impacts of the organization?
Traditional Production Line	• Do you also work before the Industry 4.0 adoption? • What was your role? • May you describe the traditional production process?
Adoption Process	• How was the adoption process of Industry 4.0? Does the management include workers in this process? • Are you afraid of losing your job due to these novel technologies?
Economic Value of Industry 4.0 adoption	• What is the economic value of the Industry 4.0 technologies? • Do you increase the output of production? • Do you increase the quality of the products?
Environmental Sustainability	• How do Industry 4.0 technologies mitigate the environmental impacts of the organization?
Social Sustainability	• What are the benefits of Industry 4.0 adoption on the workforce? • How do your work conditions change after the Industry 4.0 adoption?
Concerns of Industry 4.0 automation	• Do you consider that the automation of Industry 4.0 facilitates your work? Why and how?

Table 27 Interview track for workers

Appendix B

Table 28 shows the most significant excerpts for the dimensions of the analysis.

Topic	Coded material
Reduction of energy usage and natural resources	The company has an ISO 14001 certification. They reduced usage of water, heat and energy through an efficient production process and installed solar panels (Case A, web article).
	We recover heat from the oven in order to dry chalk moulds for the next phase saving energy. Also, we recover and reuse all the water employed in the production. We filtered this water; thus, we can use it for the next production (Case A, CPO).
	CPS retrieve the orders and optimize the wood panelling, saving wood, which came from certified sustainable farms. CPS also integrate available parts. The production process now runs without interruptions avoiding energy waste (Case B, CPO).
	We automated the outbound logistic phase, and we group orders to reduce transports and movements within the organization—also, the automated warehouse help with this objective (Case B, CPO).
	We reduced usage of paper along the production process thanks to the IS in Tablet and also administration unit now is paper-less because workers are completely digitalizing it (Case D, CTO).
	The key to sustainability is to control with information systems the process; thus, we can reduce paper and prepare alert in case of workers to make mistakes, thus reducing production waste (Case D, CPO).
	With smart sensors, we can prevent the break of cylinders. We esteem than a damaged cylinder cost us 1500€ in electricity (Case E, Mechanical Maintenance 2).
	We digitalized all the documents, the schedule of the orders by the MES thus we have reduced the papers (Case E, Informatics Engineers 1).
Reduction of waste and faulty products	We automate the handling of products by autonomous forklifts with a resulting reduction of damaged products that cannot be reprocessed and therefore waste (Case A, CEO).
	Our client sends us top-quality leather. We reduced leather wastes from productions through the competences of workers since it is not possible to automate this process (Case C, CPO).
	The automated cutting machine passes the products to the mechanical arm, which drop then in a cart, reducing the number of damaged products (Case B, worker).
	We set challenging quality goals related to faulty products since the production drastically reduced the defects rate (Case E, Quality Manager).
More Sustainable Products	In the R&D laboratory, they are continuously testing new and sustainable mixture to produce ceramics (Case A, CPO).
	Case B is environmentally friendly. They have an ISO 14001 certification and employs sustainable wood with FSC certification (Case B, web article).
More Efficient Production process	This I40 application is the first in the ceramic industry. We risked a lot, but now our production increased by 30%. We increased control over the processes, and we also produce high-quality products (Case A, CEO).
	I am making tests to find the best conditions for baking ceramic to improve quality. We will program the robots on the assembly line according to the parameters I will find (Case A, R&D Worker).
	I40 application cuts move and store parts efficiently by an automated cutting machine, a mechanical arm and a pioneer automated warehouse. We

Topic	Coded material
	now produce in-house all the goods according to the orders we received (Case B, CPO).
	The innovative production system, which the company is a pioneer in the adoption, is positively impacting economic performance, reducing time spent on each product production (Case B, web article).
	We required a technology that allows us to improve our crafting skills rather than to replace workers as this technology would be a replicable asset. We increased our production quality (Case C, CEO).
	We self-manage the production with Tv monitors because now we know how much we produce per day. Also, the competence patterns in the tablet help to improve our works (Case C, Worker).
	Case C has become one of the most innovative companies in the leather industry. Case C increased the turnover by 10% through an innovative production system (Case C, Web Article).
	The workforce role is changing as now they use new technologies that require more knowledge and specializations for their tasks. The manufacture of products increased (Case D, Web recorded interview).
	The mechanical arm is in charge of the first part of the prosthesis production, improving productivity and reduce time spent on production. The worker now is a supervisor of the technology (Case D, CTO).
	The gain of the I40 line was a constant production, and we reach 800 pieces per day while before we only produced 400 pieces (Case E, CPO).
	We increased the productivity of the line with the cobots which assemble a part of the switch components faster than workers (Case E, COO).
Better circulation of information	Now we integrate information flow through these technologies along the production process. With this technology, we reduced damaged products from 30% to 9%, maintaining the production constant without mechanical issues (Case A, CPO).
	This technology integrates the production process with the warehouse. We always now which available products we have in our warehouse (Case B, CPO).
	We integrate outbound logistics with the supplier system; the supplier can send a suitable truck to transport the products (Case B, CPO).
	The IS improved data circulation among the organizations; we can now track the products advancements for each product (Case C, CPO).
	The tablet IS interconnects the organization providing statistics of the production process. The application measures better our processes, particularly production advancement (Case D, CPO).
	All the units are integrated with the MES, and the management has current data of the production (Case E, Informatics Engineers 3).
	We reduce the intervention time from 9 to 20 minutes thanks to the systems (Case E, Informatics Engineer 2).
	I am supervising these machines producing ceramics. The work I do now is less manual and more mental. I can activate and deactivate the machine, and I try to figure out if there is a better way to let it work (Case A, worker).
	I am teaching my colleague to use this technology. In six months, he will be independent (Case B, worker 1).
	Before the work was 90% manually, we moved too many parts. Now I supervise the machine that does these hard tasks with two other workers while before I was alone. Now I have more responsibility as I check the quality of parts (Case B, worker 1).
	The production process remained the same, but now we can improve manufacturing because we can work in each phase of productions. We have more responsibilities now (Case C, Worker).

Topic	Coded material
	Some of us were moved from the production line to manage the mechanical arm. We received vocational courses to use the software of a mechanical arm (Case D, Worker).
	My unit, the maintenance, did scouting of these technologies, and then we programmed the cobots and vision system. Before, we only fix machines (Case E, Mechanical Maintenance 1).
	Along the line, the worker performs quality control of the assembly of the previous worker (Case E, CPO).
	With AR application, workers do simple maintenance activities because the AR application does visual instructions (Case E, Industrial Engineer 2).
	Now workers have to supervise the cobot, which has micro collisions and their work is very important. Sometimes cobots break the piece of the vision system has problems. They afford to restart or block the system. They help each other and charge components on the line (Case E, Mechanical Maintenance 1).
Better Work Condition	Workers thanks us for these technologies. Now, the worker is close to the mechanical arm. In case of mistakes of the mechanical arm, he can detect them and halt production. The temperature is now more adequate in the production process (Case A, CPO).
	Before we worked with a scorching temperature, now, these technologies improved our conditions mitigating the temperature (Case A, worker).
	Look, the production technologies are inside this cage which block powders of productions and sawdust is sucked from that hole. The workplace now is cleaner (Case B, CPO).
	Workforce activities are enjoying significant improvements in the day-routine activities through the innovative production system (Case B, web article).
	Workers now always know the advancement of production; they do not spend time searching paper along with the production phase (Case C, CPO).
	We automate the first part of the prosthetist production with a mechanical arm in a separate room. Now the workplace has fewer production powders (Case D, CPO).
	The redesign of the line, thanks to I40, makes the workstation more organised and ergonomics (Case E, Supply Chain/Operation Engineer).
	Along the line, we automated by cobots an assembly phase that released microplastic. Now the line is safer because these microplastics remain in the cobots area, and the worker does not inhale them (Case E, Mechanical Maintenance 1).
Workers with proficient competences	The company improves workforce conditions through I40. The worker has been requalified now they are technology experts. Now technologies move product in automation, and workers control the system through a computer Case A also provides several vocational courses for workers (Case A, web recorded interview).
	R&D workers have increased their knowledge of raw materials for ceramics thanks to vocational training and their experiments here (Case A, CPO).
	I attended vocational courses for more informatics competences. Now I place parts at the entrance of an automated warehouse, which store parts and I control the system in front of the computer before I moved and stored parts into the warehouse by forklifts (Case B, worker 2).
	Workers positively accepted the technologies as they realize how much produce for organisations. They know better all the steps of productions (Case C, CPO).

Topic	Coded material
	We provide vocational courses if workers spend too much time on tasks or commit a production mistake. Vocational courses are excellent. Our region government also certifies them (Case C, CHRO).
	The company won a price for the academy, which intensified the competences of workers through vocational courses and provided guidance for apprentices (Case C, Web Article).
	The worker supervision the machine has artisan competences in crafting the prosthesis and acquired further competences in the usage of technology through training courses (Case D, CPO).
	The organisation provides several vocational courses both for using cobots but also to work in the new assembly line. We provide them to apprentices and, for experience, workers periodically (Case E, Public Relation Officer).
	We received courses and training on the job to manage the cobots. We learnt how to block the robots and how to restart them. Also, we mentored other workers to use these technologies (Case E, Supervisor Worker 2).
	For the maintenance unit was a challenge to program the cobots, we followed a course for coding. This coding skills and our knowledge of machine anomalies really help us set up the cobots (Case E, Mechanical Maintenance 1).
New Business Unit	We settled the R&D laboratory. They search a sustainable and enduring mixture to use for our production. We hired workers to maintain the laboratory, and we provide vocational courses to them each month (Case A, CPO).
	We settled a new laboratory for materials research. We are the first in the ceramics industry (Case A, CEO).
	Did you see the new production unit? It is in a different plant since it required more space than before. We adopted new cutting machines and an automated warehouse. (Case B, CIO).
	Management settles an IT unit to develop our IS on a tablet. The IT units also manage the gather data providing statistics regarding our production process and the worker performance (Case C, CEO).
	This is the IT unit; all the IS retrieve all the data in this database. We can analyse data in real-time. We can analyse both the daily production and each worker's daily and monthly performance (Case C, CPO).
	The Digital Administration unit became important. We hired two workers to move in digital all the admirative bills. We also integrate this system with the production process IS (Case D, CTO).
Simpler activities for workers	The AR application guides workers during the maintenance activities providing visual aid and digital instructions (Case E, Industrial Engineer 2).
	Now workers only perform a phase of very easy assembly activities, before the production was more difficult because they assembled the entire product (Case E, CPO).
	The MES automatically download the orders from the corporate SAP and manage orders to reduce the repetition of activities for the charging of components (Case E, Informatics Engineer 1).
Sustaining Knowledge of production process	We have a very quick job rotation. Every day workers change the activities since they change the workstation of the line (CPO).
	To make the work less repetitive, we have a very large job rotation (Case E, Industrial Engineer 1).
	When the components change in weight and shape, cobots often has problems assembly them. So, we help the line using a worker for cobots activities (Case E, CPO).
	I work in both line, the I40 line and the manual, altering with the other workers; thus, I can assemble the entire products (Case E, Worker 1).

Topic	Coded material
	The tracking system allows finding in which assembly phase workers perform below standards. Thus, we propose courses to increase skill and knowledge for those phases (Case E, Quality manager).
	We create a quality gate along the line. The worker checks the assembly of the previous worker addressing potentially assembly problems. Thus, workers can help the team to improve their production skill (Case E, Quality Manager).
Reduction of repetitive activities	I40 for us is a way to improve efficiency and to stimulate workers. We automated repetitive assembly activities with cobots. They assemble three small parts. Workers can do more complex activities (Case E, COO).
	Along the line, we automated by cobots assembly phases repetitive and unhealthy for workers (Case E, Mechanical Maintenance 1).
	We automated with cobots only activities with low value-added where errors often occurred. Workers were excited about this (Case E, CPO).
	We automated repetitive activities through cobots where mistakes often occurred (Case E, Products engineer).
	The maintenance unit reduced their routine activities, assembly line workers with AR do these simple activities (Case E, Mechanical Maintenance 1).
	Now the logistics reduce the time spent on the trips in the plant since the forklift is programmed to do so (Case E, Supply Chain/ Operation Engineer).
Knowledge reduction of the production process	Workers do not know well the production process, especially activities to repair the products (Case E, CPO).
	The traditional production process pushes workers to know all the activities of the entire production process, while with new workers know only a small part of the production process (Case E, CPO).
	At the end, this way of producing consists of only repetitive activities and not a production like in the traditional method (Case E, Worker 2).
	In the traditional line, we knew which product we assembled, I made it, and I know how I assembled it. If there are some problems and the customer send it back, I can understand my errors and improve my way of assembling. Now, it is possible because I only put some parts of the switch and in case of errors, we don’t know who made the errors. We only do movements not assembling (Case E, Workers Supervisor 1).
	Since cobots assemble product constantly, we firstly teach how to assemble manual phases than in case of the problem of cobots. We teach the cobot phases (Case E, CPO).
	The I40 production line does not allow workers to acquire proper knowledge of ceramics because they do not conduct manual tasks. They do not touch products, but they supervise the machine (Case A, CPO).
Lack of digital competencies to handle I40 technologies	Our expert workers do not have these capabilities to work with these technologies. Instead, they have manual crafting competencies (Case A, CPO)
	Both the new workers and the experienced workers we have in the organization do not have digital competencies (CASE B, CPO).
	We programmed the traceability systems software, and at the beginning, workers know how to use it (Case C, CIO).
	We gradually implement the system because many people do not possess the right competencies to work with it (Case D, CTO).
	We teach workers since they are not familiar with the feature of these technologies (Case E, Mechanical maintenance 1).

Topic	Coded material
	Workers need to have competences for working with these technologies beyond the operative skills. But it is difficult to acquire them (Case E, Worker 2).
	We need workers also for the assembly line with informatic competences. Now it is a prerogative to be hired (Case E, COO).
Reduction of human activities	Down the assembly line, the technologies automate all the manual activities of the workers. The pieces of machinery can conduct all the production (Case A, CPO).
	Now we automated all the production activities because our I40 application allows us to cut the woods and move all the semi-finished products along with the production (Case B, CPO).
	Workers are now in charge of conducting manual activities and not support activities like the fill of the production lists (Case C, CEO).
	We automated the first part of the production process. Workers do not conduct any manual activities like before. Due to the traceability systems, workers do not fill the production lists (Case D, CTO).
	Now workers conduct only part of the production, the customization part, while before, they also crafted the shape of the prosthesis (Case D, CIO).
	Now our line has cobots. Cobot does the work of one or two people (Case E, Worker Supervisor 2).
	We design the new assembly line without a human workstation which we substituted with a cobot that performs faster (Case E, Mechanical Maintenance 1).
	Now logistics do not drive the forklifts which are moving in autonomy (Case E, Products Engineer).
	Now we are focused on programming cobots rather than does routine maintenance on the line (Case E, Mechanical Maintenance 1).
	Workers of the assembly line perform simple maintenance activities on the line which were previously performed by the maintenance unit (Case E, Informatics Engineer 3).

Table 28 Sample of coded materials

Appendix C

Table 29 illustrates the list of acronyms, which are contained in the dissertation.

Acronym	**Description**
I40	Industry 4.0
CAQDAS	Computer-assisted qualitative data analysis software
EBITDA	Earnings before interest, taxes, depreciation, and amortization
MES	Manufacturing enterprise system
ERP	Enterprise Resource Planning
AR	Augmented reality
CPO	Chief Production Officer
COO	Chief Operation Officer
CHRO	Chief Human Resources Officer
CQO	Chief Quality Officer
CEO	Chief Executive Officer
CIO	Chief Information Officer
IT	Information Technology
IoT	Internet of Things
R&D	Research and development
RFID	Radio-frequency identification
PLC	Programmable logic controller

Table 29 List of acronyms