

The Fourth Industrial Revolution Technologies – Industrial Internet of Things - and their Role in Developing the Product-service Business Model in the Industrial Sector of the Circular Economy

تقنيات الثورة الصناعية 4.0 - إنترنت الأشياء الصناعي - ودورها في تطوير نموذج الأعمال خدمة-منتج في القطاع الصناعي للاقتصاد الدائري.

* *Amira Bahri*

Amira Kalkoul

El hadj Lakhdar University – Batna1(Algeria).

Laboratory of Economic Studies in Local Industry

amira.bahri@univ-batna.dz

amira.kalkoul@univ-batna.dz

Received: 25/03/2025

Accepted:26/04/2025

Published;30.04/2025

Abstract : This study aims to explore the role of Industrial Internet of Things (IIoT), a cornerstone of the Fourth Industrial Revolution technologies, in developing the business model under the product-service system to foster the advancement of the industrial sector within the circular economy. Employing a deductive approach with descriptive and analytical tools, the study seeks to highlight the contributions of IIoT in enhancing the business models of industrial organisations that have adopted the circular economy as a philosophy and operational approach.

Keywords: Industry 4.0, Industrial Internet of Things, Product-service Business Model, Circular Economy

JEL classification codes: O33, L86

1. Introduction

1.1. Preface

The linear logic of the existing industrial model, which involves the extraction and utilisation of resources for product manufacturing followed by consumer disposal at the end of their shelf lives, is a source of numerous environmental issues, economic strain, significant price volatility, and poses a substantial challenge to resource sustainability. This has encouraged countries and companies to adopt a circular economy, which has garnered growing agreement in political and corporate spheres globally. Proposals for more resource-efficient industrial models have emerged, emulating the cyclical activities of ecosystems that operate without the notion of waste. This has prompted factories to pursue novel business models that include the principles of a circular economy. These business models have attained a unique status in the circular economy as instruments for fundamentally transforming corporate practices and advancing social and environmental innovation.

Conversations and activities advocating for the digital transformation of manufacturing facilities have proliferated among scholars, industries, and governments globally. In 2011, Germany was the first to openly designate the digitalisation of industry as "Industry 4.0." The convergence of Industry 4.0 and the circular economy has emerged as a prevalent research focus in recent years, with numerous scholars investigating the potential transition to intelligent manufacturing to facilitate circular economy initiatives. This setting highlights the intelligent product-service system driven by the Industrial Internet of Things (IIoT) as a business model that aligns circular economy trends with the economic, commercial, and manufacturing goals of the industrial sector.

1.2. Research problem

Based on the above, this research paper attempts to tackle the following problem: **What is the role played by the fourth industrial technologies - Industrial Internet of Things—in developing the product-service business model in the industrial sector of the circular economy?**

1.3. Sub-questions

The sub-questions arising from the above-mentioned problem are as follows:

- What does circular economy mean in economic thought?

- What is the relationship between Industry 4.0 and the circular economy?
- What developments has the Industrial Internet of Things brought to the business models of industrial organisations to adopt the circular economy?
- How does a smartproduct-service system help the circular economy?

1.4.Research hypothesis :

The following is the basic hypothesis of the study:

The introduction of Industrial Internet of Things technology leads to the development of a product-service business model in the industrial sector of the circular economy.

1.5.Importance of the study:

The significance of the study resides in illuminating a paramount issue of the era that disrupts society on both micro and macro levels. Environmental pollution and resource depletion have emerged as concerns for all economic agents globally. Given the major developments in technology within the industry, it is prudent to leverage this progress to foster a sustainable economy that addresses the needs of diverse stakeholders.

1.6.Research objectives:

The study tends to reach the following objectives:

- Explore the extent to which economic thought adopts the concept of the circular economy.
- Explore the innovations in business models regarding the manufacturing process so that they are aligned with the goals of circular economy visions.
- Identify the extent of using Industry 4.0 technologies, especially IIoT, to create a business model within the smart product-service system.

1.7.Research approach:

In this research, the deductive approach was adopted using the tools of analysis and description.

2. Theoretical Background of the Research

2.1.Circular economy in economic thought

The concept of circular economy is a recognition of the need to pay attention to the finite resources of the planet. Because the industrial sector is among the main economic sectors, the

sustainability of resources is the basis of its survival, which has made the circular economy a structured philosophy and thought in economic thought itself.

2.1.1. Economic history of the circular economy

John Stuart Mill, the economist and philosopher, advocated for a static economy characterised by stable population levels capable of sustaining a constant capital stock (halt growth) and extracting natural resources at rates aligned with the natural replenishment of those resources. Many scholars regard Boulding (1964-1966) as the originator of the circular economy concept. Boulding advocated for a closed and stable system characterised by advanced technology. This perspective arises from humanity's shift from agrarian to industrial economies, characterised by numerous threats, envisioning a transition from an open "Western economy," marked by reckless and exploitative practices, to a closed environment akin to a "space economy," necessitating alterations in consumption behaviours.

Daly (1974-2008) also called for the transformation of the economic system from a growth economy to a static one through the implementation of economic policy instruments such as resource depletion quotas because they are price parameters that can be applied gradually and continuously and will not disrupt market efficiency.

Stahel (1982) further developed the concept of a circular economy by describing an economic model consisting of a "spiral loop" that would minimise the flow of matter and energy to diminish environmental degradation without impeding growth.

The economists Pearce and Turner (1990) are among the first thinkers of circular economy concepts that focus on the principle of regeneration. They proposed a paradigm shift from linear use of the resource, product development and generation of the resulting pollution to a system that replaces pollution with renewable resources.

Another concept of the circular economy is the idea of restoration found in Hawken's *Ecology of Commerce*, where restoration activities include repair, reconstruction, and even the correction of previous mistakes (such as returning lands to indigenous people). Hawken refers to the circular economy by providing a model for estimating society waste by reclamation, reuse, or recycling. In the same vein, Hawken et al. (1999)

developed a natural capitalist approach to protect the biosphere while improving competitiveness and business profits. This concept is linked to the circular economy through the idea that natural capital should be restored and rebuilt (replenished) while preserving value through the circulation of products, materials and waste.(Patti, 2023)and (Alvarez-Risco et al., 2022).

2.1.2. Circular economy concept

Circular economy is defined by (Kirchherr et al., 2017) as "an economic system based on business models that replace the concept of 'end of shelf life' by reducing, reusing, or recycling and recovering materials in production / distribution and consumption processes, thus operating at the micro (products, companies and consumers), medium (industrial environmental parks) and macro (city, region, country and beyond) levels, to achieve sustainable development. This means creating environmental quality, economic prosperity, and social justice for the benefit of current and future generations." The study of (Kirchherr et al., 2017)presented this definition after discussing 114 definitions of the circular economy.

Although a circular economy is beneficial for nature, it is an economic strategy rather than an environmental one. As a main objective, the circular economy aims to ensure the sustainability and continuous development of the economy; in other words, while the circular economy supports the development of economies as the basis of the concept, it also considers the environment and contributes to its sustainability and provides a variety of social and political opportunities by strengthening the link between society and industry.

At the end of a product's shelf life, it must be restored because the value chain does not end with consumers. This situation leads to better alignment between organisations and customers. Thus, these organisations can better understand the needs and expectations of the public and manufacture products accordingly. Moreover, the implementation of a circular economy has the potential to create many jobs for local societies, attracting investments through the development of recovery companies. In addition, factories and organisations can save money and enhance their profitability by reducing costs through sustainable supply chains, end-of-shelf-lifemanagement, reducing input prices, reducing environmental fines, and generating waste. They can also make extra profits when selling their waste instead of disposing of it. The circular economy

opens new markets for recycling and remanufacturing. These new markets and new revenue channels create profits for existing companies and provide them with a competitive advantage among their competitors (Kumar et al., 2019).

2.1.3. Circular business models of the industrial sector

Business models and business model innovation occupy a very distinctive place in the circular economy as tools to radically change how business is conducted. The main challenge for organisations implementing the principles of this economy is to rethink their value chains and how they create and deliver value through innovative business models.

2.1.3.1. Concept of business model

The expression "business model" was initially coined by M. Jones in 1960 to denote the relationship between universities and commerce. Attention to business models increased only after 1995. This results from the global proliferation of Internet usage and the aspiration to enhance organisational profitability by integrating Internet technologies into operations to provide consumer value (Grabowska & Saniuk, 2023).

The academic literature has proposed several different frameworks for business model design and innovation. Among them, the most mentioned framework used to understand the critical factors of the business model in creating and capturing value by organisations is the CBM, proposed by (Osterwalder et al., 2010). This business model fabric provides a template to represent the business model logically, through which the organisation creates, advances, and captures value (Osterwalder et al., 2010). Thus, nine critical elements (known as business model building blocks) have been deduced, such as key partners, key resources, key activities, value proposition, customer segments, customer relations, channels, cost structure and revenue flows. These elements relate to four domains (product; customer interface; infrastructure management; and financial aspects) recognised as particularly suitable for understanding how an organisation creates, delivers, and captures value (Koshal, 2017). A good business model produces attractive value propositions for customers, achieves favourable cost and risk structures, and enables significant value to be captured by the business that generates and delivers products and services (Matt et al., 2021).

2.1.3.2.Business model innovation

Business model innovation represents the designed, new, and valuable changes that occur to the key elements of an organisation's business model and / or the structure that connects these elements. This indicates that this innovation introduces new tasks that go beyond minor modifications to the business environment of the organisation. The innovations in the business model aim to increase customer loyalty through more comprehensive or less expensive value propositions(Müller et al., 2018),thusa sustainable competitive advantage, which makes the innovation factor here a very vital area, encouraged by customer expectations and technological advancement.

The components of business model innovation are reflected in value proposition, value creation, and value capture. Value creation is the invention or re-architecture of assets and skills to generate value for use. The value proposition is the value delivered to the selected target customer group. Value capture is the ability of an organisation to capture material and immaterial value, as opposed to usage value created for potential users. This makes business models for smart and connected products different from traditional business models in terms of value propositions, revenue flows, and technologies, due to digital technologies that represent a major driver of business model transformations. They came up with new ways to create and capture value, as well as to propose new exchange mechanisms, transaction structures, and organisational forms that exceed borders. This shift manifests itself in the building blocks of the business model(Nagy & Stukovszky, 2023). Digital technologies thus contribute to increasing customer value, leading to entirely new business models and service offerings.

2.1.3.3.Circular business model innovation

The concept of circular business model emerged remarkably late in the literature of the circular economy. The term first appeared in 2006 in an article by Schwanger and Moser (2006) who explored individual types of business models for circular value creation. The concept of the circular business model emerged seven years later, coinciding with the wider dissemination of the circular economy concept by the Ellen MacArthur Foundation and the World Economic Forum (WEF) where the business model was cited as an answer to stimulate alignment issues that explain the rapid adoption

of advanced technologies and that would enable the recycling of a wide range of products and materials (Geissdoerfer, 2020).

The need to change business models was emphasised by (Muranko et al., 2017), allowing to exert a significant influence on the development of the circular economy through pro-circular behaviours, which represent an action taken due to the prioritisation of resource efficiency with the aim of supporting the growth of the circular economy. Hence, the real success of a circular economy depends on new business models that provide different opportunities for value creation and resource utilisation (Jana Hojnik et al., 2022).

One of the main challenges for organisations implementing circular economy principles is to rethink their value chains and how they create and deliver value through their business models. “Value” is a key factor in the circular economy literature as an economy that provides multiple mechanisms for value creation that are separated from the consumption of finite resources. The topic of 'value' is also relevant within the business model literature. By using circular strategies, the stages of the product life cycle can be useful for the creation of additional value for customers (De Angelis, 2018).

One of the most comprehensive definitions of a circular business model was introduced by (Frishammar & Parida, 2019) as follows:

“A circular business model is a plan in which a centralised company, with partners, uses innovation to create, capture, and deliver value to improve resource usage efficiency by extending the shelf life of products, thereby achieving environmental, social, and economic benefits.”

This definition emphasises an approach in which an organisation works with other value chain actors to create products and services based on circular economy principles.

2.1.3.4. Circular business model in the industrial sector

The past century has witnessed a concerning situation regarding the industry of boundless resource consumption coupled with a sharp rise in CO₂ emissions, which may lead to the collapse of the planet. The adoption of circular economy principles in manufacturing represents an opportunity for industry stakeholders to reduce material consumption as well as resource toxicity while maintaining and continuing their business activities. Circular manufacturing in industry refers to an approach aimed at reducing waste, resource consumption, and increasing the

shelf life of manufacturing materials and products through a circular economy model. This approach is based on the broader framework of the circular economy, which emphasises the elimination of waste by prolonging the life of products and materials and keeping them in use for as long as possible (François Fohl et al., 2025).

A circular economy is an industrial one, as the United Nations Industrial Development Organisation has explained:

“A circular economy is an industrial economy that redirects materials, parts, and products into use many times over and creates more value and waste. It is an alternative, preserving value for as long as possible, designing products to last, and reducing waste generation. It is achieved by integrating circular economy practices into traditional linear value chains” (UNIDO, 2019).

This would transform circular economy introduction activities (entrepreneurship, design thinking, innovation) into circular manufacturing solutions along the product shelf lifecycle, which are more circular and resource efficient, facilitated by enablers in politics, markets, consumer behaviour, and finance. Since the circular economy targets physical circularity (achieving the permanent use and reuse of materials at the end of their shelf life and other neglected resources), resource efficiency (reducing the generation of waste materials through efficiency in the design, manufacture, distribution, and use of products), and resource replacement (selecting and using resources that can be easily returned to natural or technical cycles), circular manufacturing solutions achieve these three results and are therefore the products of a circular manufacturing economy. These are new innovative products, technologies, materials, logistics, and use systems that bring improvements in circularity, efficiency, and replacement of resources (René Van Berkel, 2023).

Progressive business models show that some companies attempt to minimise rather than eliminate their negative impact on the environment by incorporating a certain amount of circularity for efficiency. The development of product-service systems (PSS) focused on circularity, which will be emphasised later, may open new opportunities for the transition to circular business models. Companies should be oriented towards higher quality circular strategies, starting with circular product and service design.

2.2. Smart manufacturing as a pillar of the circular economy

Smart manufacturing is a powerful tool to drive the shift towards a circular economy. By enabling organisations to make more informed decisions and improve their operations, it contributes significantly to achieving environmental and economic sustainability goals.

2.2.1. Manufacturing within Industry 4.0

Manufacturing under Industry 4.0 represents a paradigm shift in the manufacturing sector, where advanced digital technologies are integrated to achieve a new level of efficiency, flexibility, and connectivity. It makes it a must for companies seeking to stay competitive in the future.

2.2.1.1. Industry 4.0 concept

The Fourth Industrial Revolution denotes a digital transformation that globally emerged, primarily articulated by Kagermann, focusing on manufacturing and service innovation facilitated by cyber-physical systems, unveiled at the Hannover Expo in 2011. It seeks to digitise the complete manufacturing process with minimal human or physical contact, establishing smart manufacturing as the standard in a realm where intelligent devices, systems, and networks autonomously exchange and respond to information to oversee industrial production processes (Qi Lin & QiuHong Zhao, 2021).

New technologies in the Fourth Industrial Revolution are integrating the physical, digital, and biological worlds. The product-based nature of competition is changing to one based on a mix of products and services. This is due to the increasing role of technological push innovations that allow the acceleration of demand for new products and services, as well as the improvement of productivity through the value chains, through investments in new capabilities, and the rapid growth of global productivity limits themselves (Dragan Đurićin et al., 2018).

Researchers have recently shown that Industry 4.0 technologies can be grouped into “clusters” based on their use and impacts: technologies adopted to improve processes and work-related activities, such as advanced robotics and augmented reality, technologies adopted to improve flexibility and allow for customisation, such as additive manufacturing and other flexible machines and tools to support digital manufacturing; technologies related to data processing, such as the cloud, big data analytics, and

IoT solutions, which are closely related to the smart factory concept (Bettiol et al., 2024) that is the subject of our study.

The use of Industry 4.0 technology allows for faster interaction with market demands, providing greater supply. Cost reductions also represent economic savings that occur due to increased efficiency or the redistribution of resources as a result of Industry 4.0. In addition to increasing production capacity due to improving productivity and thus the ability to provide a larger offer, especially since this industry helps to reduce defects, increase quality, and reduce delivery times resulting from decreasing design times (Zangara et al., 2023).

2.2.1.2. Industrial Internet of Things

The Internet of Things (IoT) refers to a framework wherein billions of resource-limited entities are interconnected to the Internet and engage autonomously. The proliferation of linked devices in IoT solutions enhances the intelligence of their surrounding environment. A software broker serves a pivotal function, as it is accountable for the majority of the intelligence in IoT, integrating data from devices, facilitating communication, and enabling decision-making based on the collected data. The IoT software broker's reference architecture model is examined, outlining the optimal operating strategy for each suggested module and recommending essential security characteristics for this software type. This considers the requirements of IoT platforms (Aradhana Behura et al., 2022).

IoT systems are useful in a wide range of applications, including industrial systems where sensors are used to monitor the industrial processes themselves - product quality - and the condition of equipment (Serpanos & Wolf, 2018). This development is largely attributed to General Electric (GE), where Accenture and GE defined it in a joint report, as an architecture that enables companies to use sensors, software, machine-to-machine learning and other technologies to collect and analyse data from physical objects or other big data flows - then use these analytics to manage operations and in some cases to deliver new value-added services.

After the Industrial Internet evolved into the Industrial Internet of Things (IIoT), it is defined as a system consisting of interconnected intelligent things, cyber-physical assets, associated public information technologies, and optional cloud or terminal computing platforms, which enable real-time access, intelligence, autonomy, collection, analysis, communication and exchange of

information related to the process, product or service, within the industrial environment, in order to improve the total value of production (Theo Lynn et al., 2020).

2.2.1.3. Smart manufacturing

Manufacturing is an established industry that converts raw materials into products through a series of processes and activities, such as product design, raw material supply, and material processing. The industry is facing constant changes, new technologies, new processes, new consumer requirements, making manufacturing increasingly complex and dynamic.

For this purpose, new technologies, methods, and efficient processes have been developed and applied to transform raw materials into products, thereby adding value. Smart manufacturing, within Industry 4.0, refers to a next-generation manufacturing model that uses intelligent sensors, cloud computing infrastructures, artificial intelligence, machine learning, additive manufacturing and / or advanced robotics and IIoT specifically to improve manufacturing productivity and cost efficiency (Paul D. Clough & Jon Stammers, 2021).

IIoT helps improve the manufacturing process by reducing downtime, thereby reducing costs. It also enables inventory tracking, supply chain management and predictive maintenance based on identifying potential equipment failures before they occur in machinery and production equipment. This allows plant managers to provide a maintenance schedule, and enables real-time monitoring, analysis, and decision-making using AI and machine learning algorithms. Sensors can be used to track temperature, humidity and pressure at the production facility. This makes it possible to reduce environmental pollution and increase flexibility to respond quickly to changes in market demand to keep the organisation competitive in complex marketing conditions (Soori et al., 2023). This paved the way for the transition from the traditional manufacturing to the smart one.

2.2.1.4. Circular smart manufacturing

Manufacturing within a circular economy requires cleaner production arrangements, the adoption of renewable technology and knowledge, and the development of appropriate policies and tools. IoT enables these goals by automatically monitoring resource efficiency during production as well as at the end of the remote

usage cycle, providing huge data that enables analytics aimed at making all parts of the value chain more efficient. Thus, the link between circular economy needs and IoT value drivers is critical to minimising environmental impact. Pacelli et al. (2018) revealed how IoT can support the circular economy by developing a marketplace for connecting buyers and sellers of manufacturing services, raw materials, and products within global supply chains (Rejeb et al., 2022).

2.2.1.5. Smart factoryPSS business models

Industry 4.0 is pushing organisations to shift from a product mindset to a service one, among which are factories that must expand their role in the value chain by expanding their products with services so that they don't have to compete solely on the cost of manufacturing. The result is the so-called product-service system (PSS) concept, a framework that describes the integrated development, realisation, and demonstration of specific packages of products and services as a solution for the customer.

As a result, suppliers, customers, and other partners become part of an interconnected ecosystem around a cyber control system. Accordingly, traditional product sales-oriented manufacturers feel an increasing need to review their existing business models in response to new competitive dynamics and take advantage of industry 4.0-inspired opportunities to create new and more flexible value propositions to respond to customer demands, such as the provision of individual products and even the production of small batch size lines. Moreover, the improved client orientation is demonstrated by the expansion of innovative service offerings (Ibarra et al., 2018).

2.2.2. Industry 4.0 and the circular economy

Integrating Industry 4.0 in the circular economy represents an opportunity for sustainable economic growth. By leveraging advanced technologies, organisations and countries can build more resilient and sustainable economies.

2.2.2.1. Industry 4.0's relationship to the circular economy in the industrial sector

The ideology behind the Lean Manufacturing philosophy aligns with the goals of the circular economy, which is based on two fundamental pillars: reducing waste and creating value for the customer. From the perspective of the philosophy of flexible manufacturing, the first pillar consists of eliminating all activities that do not add value to the production process, do not improve it, do

not improve product quality, and do not reduce costs. Incorporating Industry 4.0 technologies with the Lean Manufacturing philosophy, the manufacturing process has the potential to significantly enhance the effectiveness of Lean Manufacturing methodologies, allowing industrial organisations to improve their production processes and further reduce waste. Real-time data and analytics provided by Industry 4.0 technologies allow them to make data-driven decisions and identify areas where waste can be reduced. By adapting their products to meet the specific needs and preferences of their customers, industrial enterprises reduce the likelihood of unused or unwanted products ending up in landfills.

The second pillar suggests that through Industry 4.0, organisations can collect and analyse customer data to gain insights into their preferences, behaviour, and needs, using this information to design and manufacture products tailored to their individual needs. This will in turn reduce product waste as well as unsold products, which generate high costs to manage in warehouses. Furthermore, leveraging Industry 4.0 technologies to create new business models or innovate existing business models to support the circular economy, organisations that want to adopt the circular economy model can transform their value proposition, which can be facilitated using Industry 4.0 technologies, integrating Industry 4.0 in the circular economy.

2.2.2.2. Service-product business model in circular economy

In the editorial of the special issue of the Industrial Ecology journal on the circular economy, the PSS was highlighted as a way to facilitate the circular economy by extending product shelf life and product engagement (Kjaer et al., s. d.). The PSS is an integrated offering for each, providing value to customers through value creation components in an innovative business model that takes into account the needs of stakeholders (Henrique Rozenfeld et al., 2021).

A PSS oriented towards business models enables the implementation of circular economy principles by promoting a new perspective on the role of resources in the economy as it changes the traditional view of resources from being consumed to being assets that can be reused and recycled. It also encourages the development of more flexible supply chains capable of reusing materials and

extending the shelf life of products. It pushes organisations to design products that can be easily repaired and recycled.

PSS uses IT to track products and manage their shelf life cycles, contributing to circular economy goals(Kühl et al., 2018). Its association with Industry 4.0 technology makes it a smart product-service system.

2.2.2.3.IoT and smartPSS in the circular economy

Smart PSS is a type of business model that integrates smart products and services into a solution package using digital technologies to meet individual customer needs in a sustainable manner, and different ownership configurations motivate suppliers to design products for resource efficiency and longevity(Ries et al., 2023)(drafted in 2014).

PSS,enabled by IoT, has been powered as the key technology to drive digital transformation. The IoT-enabled PSS was first introduced through the exploitation of RFID devices in the industrial environment, where product RFID readers/tags and their embedded information are connected to the Internet for the purposes of production maintenance (digital service). Furthermore, the platform approach has been adopted as an organisational business perspective to leverage the value of IT-enabled interactions and modular transaction-based digital technologies. Thus, at this stage, the main concern goes beyond the efficient delivery of data/information as in Internet-based PSS, but also taking into account both the online information processing capacity and the modular service configuration (cloud services) of digitisation and service (Ries et al., 2023).

PSS, which are circularly oriented, provide new opportunities for a shift towards circular business models. The PSS emphasises the idea of product safety, durability, regeneration, and fostering a shift from product ownership to service-based use. PSS also involves a return flow to the product from users, as companies have an incentive to extend the shelflife cycles of products, ensure that they are used as intensively as possible, make them as cost-effective and efficient in using materials as possible, and reuse parts as much as possible after the end of the product's shelf life. In addition, manufacturing industries have different product shelf life cycles and different consumption patterns, leading to a variety of circular practices. Focusing on slowing down cycles by offering products as a service to users increases resource use efficiency through reuse, as

well as increasing functions related to economies that support this service model.

3. Conclusion

This study attempted to reveal the role of the technologies of the Fourth Industrial Revolution - Industrial Internet of Things - and their role in developing the service-product business model in the industrial sector of the circular economy.

The IoT-enabled PSS has been found to be an innovative business model that connects products and services via IoT technologies. Such correlation allows for the collection and analysis of vast amounts of data on product performance and usage, enabling companies to provide customised services to customers and improve the efficiency of operations.

Furthermore, IoT-enabled PSS contributes to circular economy goals by extending the shelf life of products, improving resource use efficiency, and developing sustainable products. Simply put, this model represents a shift from focusing on selling the product to delivering ongoing value to the customer, taking into account environmental and economic impacts.

4. Bibliography

- Alvarez-Risco, A., Rosen, M. A., & Del-Aguila-Arcentales, S. (Éds.). (2022). *Towards a Circular Economy: Transdisciplinary Approach for Business*. Springer International Publishing. <https://doi.org/10.1007/978-3-030-94293-9>
- Aradhana Behura, Suneeta Satpathy, Sachi Nandan Mohanty, & Jyotir Moy Chatterjee (Éds.). (2022). Internet of Things: Basic Concepts and Decorum of Smart Services. In *Internet of Things and Its Applications*. Springer International Publishing. <https://doi.org/10.1007/978-3-030-77528-5>
- Bettiol, M., Capestro, M., Di Maria, E., & Ganau, R. (2024). Is this time different? How Industry 4.0 affects firms' labor productivity. *Small Business Economics*, 62(4), 1449-1467. <https://doi.org/10.1007/s11187-023-00825-8>
- De Angelis, R. (2018). *Business Models in the Circular Economy*. Springer International Publishing. <https://doi.org/10.1007/978-3-319-75127-6>
- Dragan Đuričin, Iva Vuksanović Herceg, & Dragan (Éds.). (2018). Industry 4.0 and Paradigm Change in Economics and Business Management. In *Proceedings of 3rd International Conference on the*

- Industry 4.0 Model for Advanced Manufacturing*. Springer International Publishing. <https://doi.org/10.1007/978-3-319-89563-5>
- François Fohl, Vlatka Rajčić, Viorel Ungureanu, Lidiana Arrè, Ungureanu, & Raluca Buzatu (Éds.). (2025). Circular Manufacturing. In *Circular Economy Design and Management in the Built Environment : A Critical Review of the State of the Art* (p. 69-91). Springer Nature Switzerland. <https://doi.org/10.1007/978-3-031-73490-8>
 - Frishammar, J., & Parida, V. (2019). Circular Business Model Transformation: A Roadmap for Incumbent Firms. *California Management Review*, 61(2), 5-29. <https://doi.org/10.1177/0008125618811926>
 - Geissdoerfer, M. (2020). Circular business models : A review. *Journal of Cleaner Production*.
 - Grabowska, S., & Saniuk, S. (2023). *Business Models for Industry 4.0: Concepts and Challenges in SME Organisations* (1^{re} éd.). Routledge. <https://doi.org/10.4324/9781003317401>
 - Henrique Rozenfeld, Maiara Rosa, Sânia da Costa Fernandes, Marina de Pádua Pieroni, Carolina Queiroz Souza, Érica Gonçalves Rezende, & Cristina Targas Gurian (Éds.). (2021). Product-Service Systems (PSS). In *Life Cycle Engineering and Management of Products : Theory and Practice*. Springer International Publishing. <https://doi.org/10.1007/978-3-030-78044-9>
 - Ibarra, D., Ganzarain, J., & Igartua, J. I. (2018). Business model innovation through Industry 4.0 : A review. *Procedia Manufacturing*, 22, 4-10. <https://doi.org/10.1016/j.promfg.2018.03.002>
 - Jana Hojnik, Roberto Biloslavo, & Tine Bertoncel (Éds.). (2022). Business Models for a Circular Economy : A Literature Review with Bibliometric and Topic Analysis. In *Business Models for the Circular Economy : A European Perspective* (p. 13-64). Springer International Publishing. <https://doi.org/10.1007/978-3-031-08313-6>
 - Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, 127, 221-232. <https://doi.org/10.1016/j.resconrec.2017.09.005>
 - Kjaer, L. L., Pigosso, D. C. A., Niero, M., Bech, N. M., & McAloone, T. C. (s. d.). *Product/Service-Systems for a Circular Economy*.
 - Koshal, N. S. (2017). *Understanding letter of credit : Learner's guide to letter of credit*. Notion Press.
 - Köhl, C., Tjahjono, B., Bourlakis, M., & Aktas, E. (2018). Implementation of Circular Economy principles in PSS operations. *Procedia CIRP*, 73, 124-129. <https://doi.org/10.1016/j.procir.2018.03.303>

- Kumar, V., Sezersan, I., Garza-Reyes, J. A., Gonzalez, E. D. R. S., & AL-Shboul, M. A. (2019). Circular economy in the manufacturing sector: Benefits, opportunities and barriers. *Management Decision*, 57(4), 1067-1086. <https://doi.org/10.1108/MD-09-2018-1070>
- Matt, D. T., Modrák, V., & Zsifkovits, H. (Éds.). (2021). *Implementing Industry 4.0 in SMEs: Concepts, Examples and Applications*. Springer International Publishing. <https://doi.org/10.1007/978-3-030-70516-9>
- Müller, J. M., Buliga, O., & Voigt, K.-I. (2018). Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technological Forecasting and Social Change*, 132, 2-17. <https://doi.org/10.1016/j.techfore.2017.12.019>
- Muranko, Z., Andrews, D., Chaer, I., Newton, E. J., Proudman, P., & Longhurst, M. (2017). Pro-circular behaviours and refrigerated display cabinets: Supporting resource efficiency in the retail refrigeration sector. *Energy Procedia*, 123, 70-75. <https://doi.org/10.1016/j.egypro.2017.07.235>
- Nagy, S. G., & Stukovszky, T. (2023). *Smart Business and Digital Transformation: An Industry 4.0 Perspective* (1^{re} éd.). Routledge. <https://doi.org/10.4324/9781003390312>
- Osterwalder, A., Pigneur, Y., & Clark, T. (2010). *Business model generation: A handbook for visionaries, game changers, and challengers*. Wiley.
- Patti, S. (2023). *Circular Economy and Policy: Sustainability, Environmental, and Social Perspectives*. Springer International Publishing. <https://doi.org/10.1007/978-3-031-43324-5>
- Paul D. Clough & Jon Stammers (Éds.). (2021). Smart Manufacturing. In *Smart Connected World: Technologies and Applications Shaping the Future* (p. 141-169). Springer International Publishing. <https://doi.org/10.1007/978-3-030-76387-9>
- Qi Lin, F. P., & Qiuhong Zhao, B. (Éds.). (2021). IoT Applications in Healthcare. In *Internet of Things: Cases and Studies* (Vol. 305). Springer International Publishing. <https://doi.org/10.1007/978-3-030-70478-0>
- Rejeb, A., Suhaiza, Z., Rejeb, K., Seuring, S., & Treiblmaier, H. (2022). The Internet of Things and the circular economy: A systematic literature review and research agenda. *Journal of Cleaner Production*, 350, 131439. <https://doi.org/10.1016/j.jclepro.2022.131439>
- René Van Berkel (Éd.). (2023). Circular Manufacturing Transformation: Manufacturing Perspectives, Examples, and Experiences from Implementation of Circular Economy in Asia. In *Circular Economy Adoption: Catalysing Decarbonisation Through*

- Policy Instruments* (1st ed. 2023, p. 269-299). Springer Nature Singapore. <https://doi.org/10.1007/978-981-99-4803-1>
- Ries, L., Beckmann, M., & Wehnert, P. (2023). Sustainable smart product-service systems : A causal logic framework for impact design. *Journal of Business Economics*, 93(4), 667-706. <https://doi.org/10.1007/s11573-023-01154-8>
 - Serpanos, D., & Wolf, M. (2018). *Internet-of-Things (IoT) Systems*. Springer International Publishing. <https://doi.org/10.1007/978-3-319-69715-4>
 - Soori, M., Arezoo, B., & Dastres, R. (2023). Internet of things for smart factories in industry 4.0, a review. *Internet of Things and Cyber-Physical Systems*, 3, 192-204. <https://doi.org/10.1016/j.iotcps.2023.04.006>
 - Theo Lynn, Patricia Takako Endo, Andrea Maria N. C. Ribeiro, Gibson B. N. Barbosa, & Pierangelo Rosati (Éds.). (2020). The Internet of Things : Definitions, Key Concepts, and Reference Architectures. In *The Cloud-to-Thing Continuum : Opportunities and Challenges in Cloud, Fog and Edge Computing*. Springer International Publishing. <https://doi.org/10.1007/978-3-030-41110-7>
 - UNIDO. (2019). *Industrial Resource Efficiency Division and CIRCULAR ECONOMY*.
 - Zangara, G., Cosma, A., & Filice, L. (2023). Impact analysis of Industry 4.0 in SMEs : Harmonic innovation as a virtuous evolution for the community development. *Procedia Computer Science*, 217, 1370-1377. <https://doi.org/10.1016/j.procs.2022.12.335>