(03-007) - From Industry 4.0 to Industry 5.0: A Study and Perspectives on Technological Evolution

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Historically, society has undergone inevitable changes in the economy, mindset, and surrounding nature. The influence of global events, such as climate change, highlights three crucial dimensions in industrial technological integration. Firstly, the centrality of the human being in industrial processes is emphasized, focusing on the need to place people at the center of technological strategy. Secondly, the importance of resilience in the value chain is underscored, recognizing the need to prepare for possible future natural impacts. Thirdly, the relevance of sustainability in the human ecosystem is emphasized, advocating for sustainable values in all industrial actions. This work reviews the evolution of key technologies in Industry 4.0, evaluating their application to boost economic performance and strengthen business competitiveness. As a result of the environmental footprint associated with Industry 4.0 technologies and the adoption of Sustainable Development Goals (SDG), the transition to Industry 5.0 is proposed as essential for a responsible and resilient industry, emphasizing the combination of technologies with a values-based approach.

Keywords: Industry 4.0; Industry 5.0; SDG; values, sustainability; key enabling technologies.

De la Industria 4.0 a la Industria 5.0: un estudio y perspectiva de la evolución tecnológica

A lo largo de la historia, la sociedad ha experimentado cambios inevitables en la economía, la mentalidad y la naturaleza circundante. La influencia de eventos globales, como el cambio climático, resalta tres dimensiones cruciales en la integración tecnológica industrial. Primero, se destaca la centralidad del ser humano en los procesos industriales, enfocándose en la necesidad de situar a las personas en el centro de la estrategia tecnológica. Segundo, se resalta la importancia de la resiliencia en la cadena de valor, reconociendo la necesidad de prepararse para posibles futuros impactos naturales. Tercero, se enfatiza la relevancia de la sostenibilidad en el ecosistema humano, abogando por valores sostenibles en todas las acciones industriales. Este trabajo revisa la evolución de tecnologías clave de la Industria 4.0, evaluando su aplicación para impulsar el rendimiento económico y fortalecer la competitividad empresarial. Como consecuencia de la huella ambiental asociada a las tecnologías de la Industria 4.0 y la adopción de los Objetivos de Desarrollo Sostenible (ODS), se propone la transición hacia la Industria 5.0, como esencial para una industria responsable y resistente, haciendo hincapié en la combinación de tecnologías con un enfoque basado en valores humanos.

Palabras clave: Industria 4.0; Industria 5.0; ODS; valores; sostenibilidad; tecnologías habilitadoras.

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1. Introduction

Sustainability is articulated around three vectors that define and develop the triple E strategy: Economy, Equity, and Ecology (Aguayo González et al., 2011). On the other hand, Müller (2020) argues that in its initial concept, Industry 4.0 was focused on values for humans, society, and ecology. However, over the years, it has been observed that its final destination has been very different from its initial goals. Following this line, Jiménez López et al. (2022) assert that Industry 4.0 brings about significant changes in companies, including their smart products, individualized production, autonomous control, and a new level of techno-social interaction.

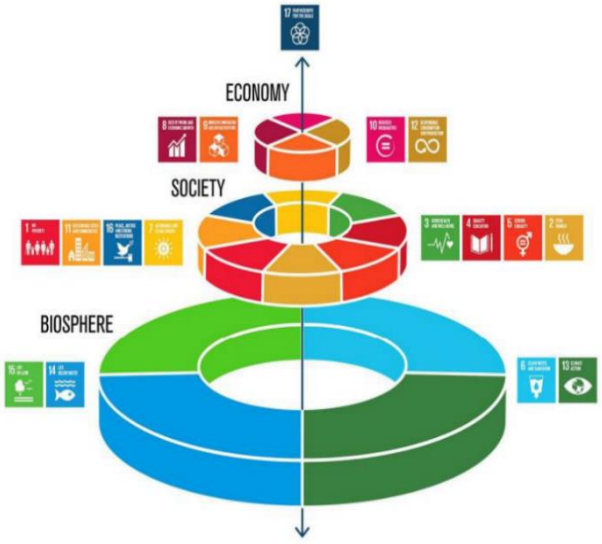
In this context, it is necessary to have a unified framework that allows for a comprehensive deployment of a Triple Balance approach across the three dimensions of sustainability based on the goals of the UN's 2030 Agenda for Sustainable Development (Ávila-Gutiérrez et al., 2022). The United Nations goals have highlighted that sustainable development is no longer an option but a necessity for the survival of organizations and communities (Varriale et al., 2023).

Here is where Industry 5.0 (I5.0) emerges, merging technological and economic demands with the social and environmental challenges inherent to the transformations of contemporary society (Mollina Navarrete & Villar Cañada, 2021), as well as providing additional value when integrated into a resilient, sustainable, and human-centered approach (Ivanov, 2023). Thus, this industry represents a strategy designed to fill the main deficiencies of Industry 4.0, combining the technologies developed in Industry 4.0 with the principles of Society 5.0 and Operator 5.0 (Slavic et al., 2024).

In parallel, Value-Sensitive Design (VSD) is based precisely on the premise that technology is not value-neutral but is sensitive to the values of different stakeholders (Longo et al., 2020). However, tracking the adoption of VSD in the industry is challenging, as most companies do not disclose their design methods (Cawthorne, 2023).

Likewise, the roadmap marked by the 2030 Agenda and the Sustainable Development Goals (Figure 1) makes us realize that persisting with the previous patterns of production, energy, and consumption is no longer viable. Therefore, it is necessary to transform the dominant development paradigm into one that leads us toward sustainable, inclusive development with a long-term vision, with these goals being a necessity for the survival of organizations and communities (Varriale et al., 2023). In this sense, the SDGs will enable us to achieve a world with a positive impact environmentally, economically, and socially (ConexionRSEDesarrollo, 2022).

Figure 1. SDGs of 2030 Agenda. Source: (Duran & Martínez, 2022)



2. Objectives

The main objective of this article is to analyze the state of the art regarding the transition from Industry 4.0 to Industry 5.0. This goal is divided into three specific objectives:

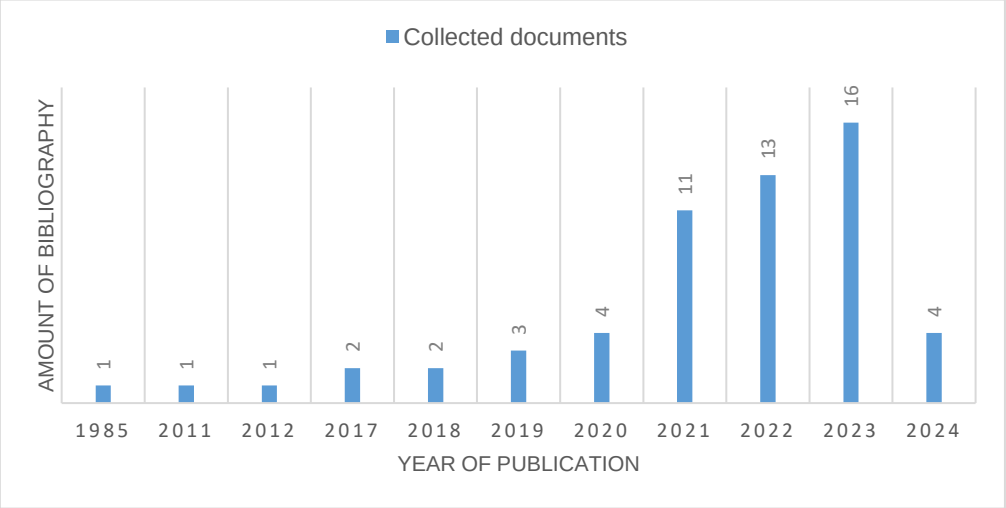
- Analyze existing literature on the advantages of integrating Industry 4.0 enabling technologies into Porter's value chain, as well as the impact of Industry 5.0 on workers and the environment.
- Examine the progressive expansion of Industry 5.0 and discuss the aspects that facilitate its implementation.
- Propose the inclusion of the Value-Sensitive Design (VSD) methodology in Industry 5.0 and its impact on achieving the Sustainable Development Goals.

3. Methodology

To achieve these objectives and in accordance with the type of publication, the following work method was adopted: publications in journals, conference proceedings, books, and book chapters from 1985 to 2024 were analyzed. This was conducted through a literature review of the Web of Science (WoS) database. The reason for selecting the year 1985 as the starting point is due to the introduction of the value chain concept by economist Michael Porter for the first time.

The results of this search have provided context for this work, noting the different approaches related to Industry 4.0 and Industry 5.0 taken by various authors. In Figure 2, the different bibliographic references included in the document are grouped and classified according to their publication date.

Figure 2. Statistics of referenced articles by publication date. Source: own elaboration.



4. Industry 4.0

The term Industry 4.0 was coined in Germany in 2011 during the Hannover Messe (Industrial Technology Fair), with the ultimate goal of achieving the digital transformation of the sector (Xu et al., 2021).

When linking the value chain to Industry 4.0, Urbina Nájera et al. (2020) argue that in the digitalization of industries, especially those adopting Industry 4.0 enabling technologies, Porter's value chain becomes a tool that enhances its strategic significance.

An example is Amazon, which has excellently combined the use of artificial intelligence to recommend products to its customers, thereby fulfilling their desire for immediacy and simplicity in online commercial transactions (Hernández Ramos & Peña Andrés, 2018). Furthermore, this company uses predictive models to understand customer purchase preferences based on online data (Kaliraj, 2022).

Another example is found in the medical implant sector, where customization has allowed for the creation of high-value implants specifically for each patient (Rubio & Díaz, 2021).

Additionally, Audi is utilizing mixed reality to increase the efficiency of its logistical planning operations (Peña de San Antonio, 2022).

Table 1 presents the general benefits associated with each part of Porter's value chain (1985) and each of the enabling technologies of Industry 4.0. Thus, these improvements represent a competitive advantage for the industry that acquires these technologies, as well as a step forward in the specified SDGs.

Table 1. Benefits of Industry 4.0 enabling technologies in Porter's value chain. Source: own elaboration.

Benefits aligned with SDGs 8, 9, 10, and 12.			
Technology	**Benefits in the value chain**		**References**
Artificial Intelligence	Operations	Predictive maintenance, production optimization	(Liu et al., 2018), (Blackwell et al., 2021).

	Outbound Logistics	Task tracking	(Lledo Yagüe et al., 2021)
	Customer Service	Chatbots, virtual assistants.	(Basulo-Ribeiro & Teixeira, 2024)
	Marketing	Implementing customer profiles, programmed advertising	(Hernández Ramos & Peña Andrés, 2018), (Lledo Yagüe et al., 2021)
	Human Resources	Automation, objectivity	(Lledo Yagüe et al., 2021)
Big Data	Inbound Logistics	Stock management	
	Operations	Product improvement	(Banerjee, 2019)
	Outbound Logistics	Predictive performance analysis	(Lledo Yagüe et al., 2021)
	Marketing	Behavior trends	(Kaliraj, 2022)
	Sales	Price management	(Banerjee, 2019)
	Company Infrastructure	Data storage	(Banerjee, 2019)
	Human Resources	Staff lists	
Cloud Computing	Inbound Logistics	Efficiency and time optimization	(Varriale et al., 2023)
	Outbound Logistics	Monitor/Store inventory	(Varriale et al., 2023)
Internet of Things and Industrial Internet of Things	Operations	Failure prediction, productivity improvements, cost savings	(Martinelli et al., 2021), (Juma et al., 2023)
	Outbound Logistics	Smooth supply chain, prevent downtime, tracking	(Mamani & Sucari, 2022)
	Customer Service	Better customer experience	(Martinelli et al., 2021)
	Sales	Better-performing products	(Martinelli et al., 2021)
Industrial Robotics and Cobots.	Operations	Productivity improvement, reduce times, real-time monitoring, task automation.	(Abril-Jiménez et al., 2024; Lee et al., 2022; Marinelli, 2022)
	Outbound Logistics	Supply tracking	(Elangovan, 2021)
Additive Manufacturing	Operations	Speed and cost reduction	(Mamani & Sucari, 2022) (Elangovan, 2021)
	Outbound Logistics	Reduce cost	(Varriale et al., 2023)
	Customer Service	Customized products	(Rubio & Díaz, 2021)
Digital Twins	Inbound Logistics	Performance and maintenance	(Mamani & Sucari, 2022) (Alimam et al., 2023)
	Operations	Reduce cost, failure prediction, downtime	(Noor-A-Rahim et al., 2023; Sindhwani et al., 2022)
	Customer Service	Remote startup and diagnostics	(Noor-A-Rahim et al., 2023)
Cyber-Physical Systems	Operations	Productivity increase, time reduction	(Boschetti et al., 2023)

Blockchain	Outbound Logistics and Customer Service	Disintermediation, order tracking, higher productivity	(Preukschat, 2017) (Adel, 2022)
Wearables	Outbound Logistics	Real-time data	(Corporativa, 2023)
Virtual, Augmented, and Mixed Reality	Inbound Logistics	Resource, materials, production cycles, and inventory savings	(De Giovanni, 2023)
	Operations	Lower cost, increased safety, efficiency boost, machinery maintenance and repair	(Montero, 2020), (Peña de San Antonio, 2022), (Martínez, 2017)
	Human Resources	Time optimization, reduced worker training	(Martínez, 2017)

With all these technologies in mind, and after a decade of navigating through Industry 4.0, the European Commission deliberated in 2021 that the industry 4.0 model is not the best framework to follow to achieve Europe's 2030 goals (Borchardt et al., 2022). In this context, the goals set by the United Nations 2030 Agenda have highlighted that sustainable development is no longer an option, but a necessity for the survival of organizations and communities (Varriale et al., 2023).

5. Industry 5.0

The European Commission has defined the concept of Industry 5.0 as the vision for industries to think beyond increasing productivity and efficiency and to contribute to society by placing workers at the center of the production process (Raja Santhi & Muthuswamy, 2023). This industry, therefore, should complement the human being, enhancing their creative thinking (Elangovan, 2021).

Table 2 shows the main differences between the two revolutions.

Table 2. Differences between Industry 4.0 and Industry 5.0. Source: own elaboration based on (Müller, 2020)

Industry 4.0	Industry 5.0
Focused on improving efficiency.	Combines competitiveness and sustainability.
Technology centered on the emergence of cyber-physical systems.	Emphasizes the impact of alternatives for sustainability and resilience.
Aligned with the optimization of business models, minimization of costs, and maximization of profits for shareholders.	Empowers workers through the use of digital devices, supporting a human-centered technological approach.
Lack of focus on design and performance dimensions essential for systemic transformation and the decoupling of resource and material use from negative environmental, climatic, and social impacts.	Builds transition pathways toward environmentally sustainable uses of technology.
	Expands the scope of corporate responsibility to all its value chains.
	Indicators that show progress made on the path to well-being, resilience, and overall sustainability.

In summary, an industry approach focused solely on the economic aspect is clearly unsustainable. For the industry to be prosperous in the broadest sense of the word, environmental and social aspects must be integrated. Thus, Industry 5.0 aims to steer the sector's development towards a production model that uses technology to be more

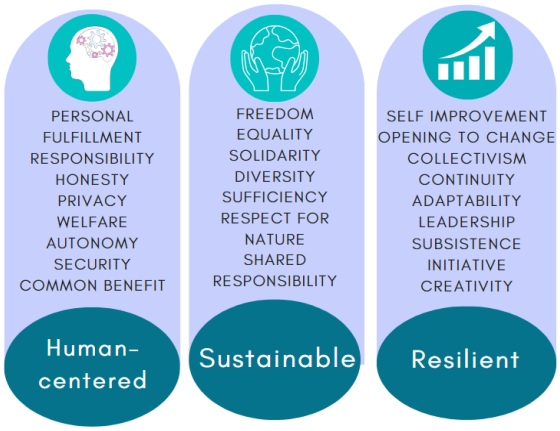
competitive, complementing the progress provided by various technologies and enhancing the positive relationship between humans and machines (Tipan & Garzon, 2023).

5.1. Industry 5.0 Values

At the same time, value creation as the central pillar of I5.0 must be aligned with the perspectives of resilience, the environmental part of sustainability, and human-centeredness (Ivanov, 2023). These values referenced by most researchers could be essential pillars in the transition from Industry 4.0 to Industry 5.0. Furthermore, these supports described are considered a step forward in achieving the SDGs (Sindhwani et al., 2022).

Figure 3 shows the different values that Industry 5.0 brings, classified into its three pillars. However, these values do not form an exhaustive list but a starting point for future studies aimed at designing systems within Industry 5.0 (Agote et al., 2022).

Figure 3. Industry 5.0 Values. Source: Adapted from (Agote et al., 2022)



In this context, three fundamental aspects are considered:

Firstly, instead of asking what we can do with technology, we should reframe the question to: what can technology do for us? Thus, producers need to recognize what technology can do for people and focus on how technology can meet the worker's requirements, not the other way around (Adel, 2022).

Secondly, industries are currently adopting practices such as sustainable supply chain management, the use of Industry 4.0 technology, circular economy, reconfigurable manufacturing systems to achieve sustainability, the use of environmentally sound materials and energy, minimizing the use of hazardous substances, and, in addition, they are in favor of biodiversity protection (Camarinha-Matos et al., 2022; Palsodkar et al., 2023).

Lastly, resilience serves as an approach to achieve greater robustness in production, ensuring that the industry can provide the necessary infrastructure and meet human needs through the use of technologies developed during Industry 4.0, which can improve the quality of the final products (Agote et al., 2022; Slavic et al., 2024).

5.2. Corporate Social Responsibility

As reinforcement to the three pillars of Industry 5.0, Corporate Social Responsibility (CSR) should be incorporated, which, when applied to company management, benefits not only the company itself but also its workers, the social environment, and the environment (García & De Bedoya, 2020).

Furthermore, according to García y De Bedoya (2020), CSR is gaining importance today as consumers are increasingly aware of social issues, thanks to the heightened awareness promoted by initiatives like the 2030 Agenda for Sustainable Development.

Thus, CSR and the SDGs should follow a converging trajectory that allows asserting that it is now possible to do well as a company by doing good for the world (Pes & Castiñeira, 2021).

5.3. Technologies in Industry 5.0

Similarly, Industry 4.0 enabling technologies provide additional value when integrated into a resilient, sustainable, and human-centered approach (Ivanov, 2023), and will greatly assist organizations in meeting the SDGs and their targets (Palsodkar et al., 2023). Thus, the new paradigm present in Industry 5.0 will make technologies serve to shift economic systems towards more social (inclusive) and green (environmental) models (Mollina Navarrete & Villar Cañada, 2021).

An example of this is exoskeletons, which have the potential to make certain tasks less physically demanding. This could allow women to take on tasks previously reserved for men due to the physical strength required (European Commission, Directorate-General for Research and Innovation, Breque, De Nul, & Petridis, 2021), thereby embodying values such as well-being and safety, in line with Figure 3, and aligned with society-related SDGs as shown in Figure 1.

Another example could be the metaverse, which promises a substantial reduction in carbon emissions in the near future by replacing physical goods with digital ones and real-world presence with virtual interactions. Specifically, Google aims to operate data centers using completely carbon-free energy by 2030 (De Giovanni, 2023). These actions relate to values such as shared responsibility, respect for nature, and sufficiency, in accordance with Figure 3, and this use of technology is aligned with the biosphere-related SDGs, as shown in Figure 1.

Table 3 breaks down a variety of benefits and values associated with Industry 4.0 enabling technologies concerning the environment and workers. These additional examples provide a fuller picture of the positive impacts these technologies can have on these two areas, as well as on the specified SDGs.

Table 3. Impact of Industry 5.0 on workers and the environment. Source: own elaboration.

I4.0 Technologies Applied to I5.0			
Benefits		**Values**	**References**
Environmental Benefits Aligned with SDGs 6,13,14 and 15.	Eco-friendly materials	Respect for nature	(Raja Santhi & Muthuswamy, 2023)
	Consumption and waste management	Integrity, equality, sufficiency, respect for nature	(Varriale et al., 2023), (Preukschat, 2017)
	Reduce transportation, waste, and carbon emissions	Equality, sufficiency, respect for nature, shared responsibility	(Ivanov, 2023), (Varriale et al., 2023), (Raja Santhi & Muthuswamy, 2023), (De Giovanni, 2023)

	Energy efficiency	Respect for nature	(Atif, 2023), (Ríos Insua & Gómez-Ullate Oteiza, 2019), (Elangovan, 2021)
	Circular economy	Sufficiency, shared responsibility	(Varriale et al., 2023)
Worker Benefits. Aligned with SDGs 1,2,3,4,5,7,11 and 16.	Alert systems (temperature, pollution, pollen)	Safety	(Preukschat, 2017)
	Prevention of injuries (Exoskeletons)	Well-being, safety, autonomy	(Marinelli, 2022), (Dirección General de Investigación e Innovación (Comisión Europea) et al., 2021)
	Accident reduction	Safety	(Agote-Garrido et al., 2023)
	Stress monitoring	Well-being, safety, common good	(Longo et al., 2020)
	Training and skill development	Personal fulfillment, autonomy	(Peña de San Antonio, 2022), (De Giovanni, 2023)
	Collision avoidance and remote work	Safety, privacy, common good	(Boschetti et al., 2023)
	Error prevention and decision-making	Well-being, safety, common good	(Verma et al., 2022), (Uppal et al., 2023), (Varriale et al., 2023)
	Workstation adjustments for disabilities	Well-being, autonomy, personal fulfillment	(Bonello et al., 2024)

5.4. Value-Sensitive Design

Value-Sensitive Design (VSD) is based on the premise that technology is not value-neutral but is sensitive to the values of stakeholders (Longo et al., 2020). That is, technology itself is neither good nor bad, and only its uses have moral or other values (Boshuijzen-van Burken, 2023).

This methodology was effectively applied in the WATER-MINING project. The presence, monitoring, and control of contaminants in wastewater pose a security problem for water reuse and resource recovery. Thus, during the first year of this project, VSD was used to identify specific stakeholder concerns, social values, and perceptions, thereby guiding the development of resource recovery technologies. The main outcome of this process was a set of design proposals aimed at incorporating social values into emerging water extraction technologies (“Deliverables”, 2021; Micó et al., 2021).

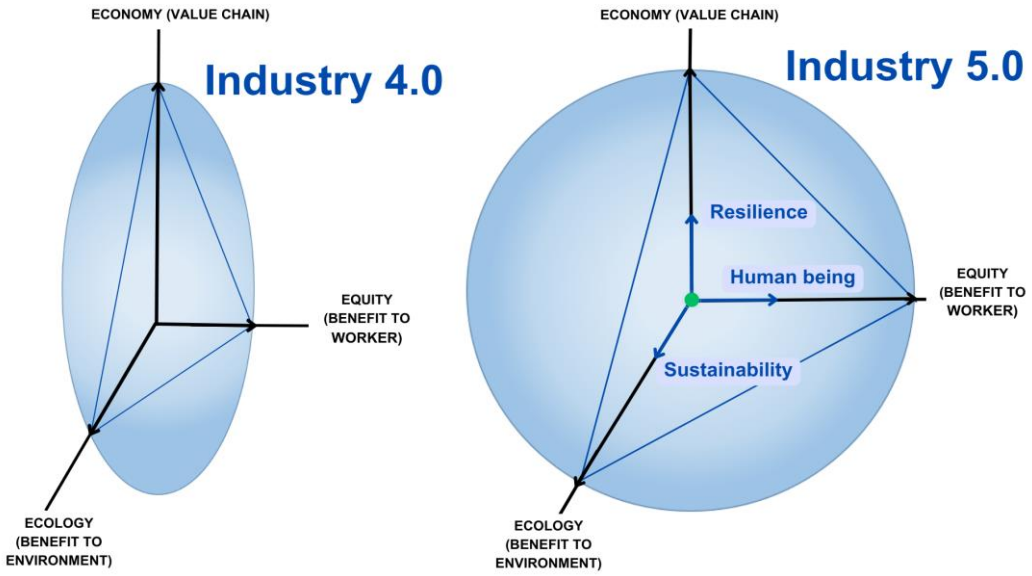
Thus, (Boshuijzen-van Burken, 2023) considers VSD a promising approach to the challenge of moral deliberations in the design of technological artifacts, acknowledging that it may sometimes be necessary to yield to one value over another to create a viable technology design.

In the same context, (Longo et al., 2020) selects VSD as the theoretical and methodological framework to guide the design of the Factory of the Future from the perspective of Industry 5.0. This choice is due, on one hand, to the emphasis on involving stakeholders in the design process and the philosophical investigation of the involved values, and on the other hand, because of the scope and applicability of VSD in different design spaces.

5.5. Sustainability Sphere

From another perspective, (Heras García de Vinuesa et al., 2012) proposes sustainability as a sphere encompassing the economic, equitable, and ecological subsystems. Based on this premise, Figure 4 illustrates the difference in sustainability that Industry 4.0 can achieve compared to the sustainability that Industry 5.0 aims to establish from its early appearance.

Figure 4. Comparison of sustainability achievements of Industry 5.0 versus Industry 4.0. Source: own elaboration.



5.6. Towards an Integrated Perspective: The Influence of VSD, the Triple E, and I5.0 on Achieving the SDGs

Accordingly, and based on Figure 4 and VSD, a conceptual model of Industry 5.0 (Figure 5) is proposed that aids in understanding the role of values in the three pillars of the new industry. It argues that, with the support of the vectors of resilience, sustainability, and human-centricity, and thanks to the enabling technologies of Industry 4.0, it is possible to achieve a positive triple balance in the economy, equity, and ecology of an industry. Consequently, the goal is to find a balance between the benefits an industry can offer to its employees and the environment, along with economic profitability.

In this line of thought, values such as safety, respect for nature, responsibility, adaptability... described in Figure 3, will be applied to achieve such balance.

Furthermore, with this purpose in mind, the industry will align with the achievement of the Sustainable Development Goals and the 2030 Agenda.

Figure 5. Sustainability Sphere Applied to Industry 5.0. Source: own elaboration.

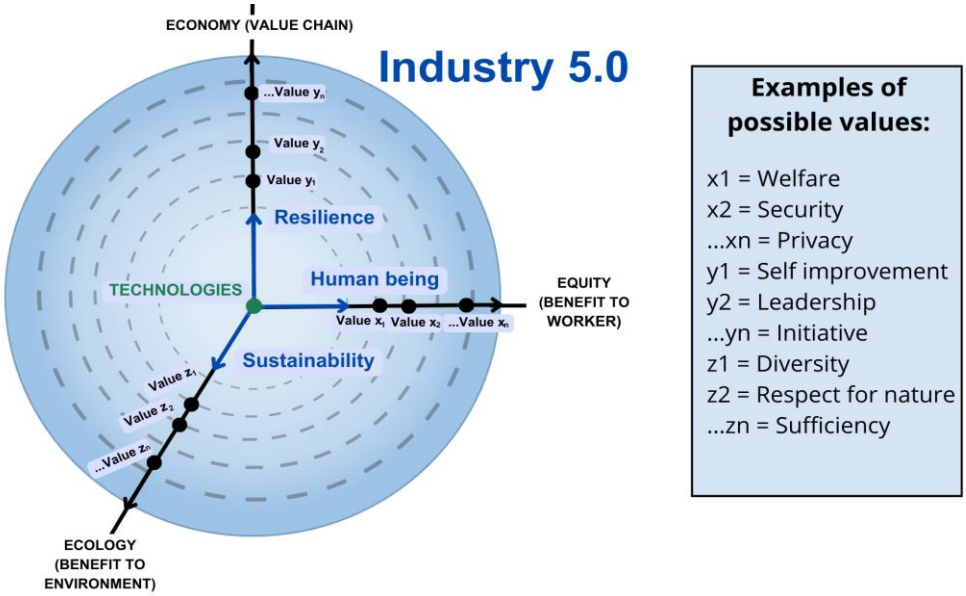
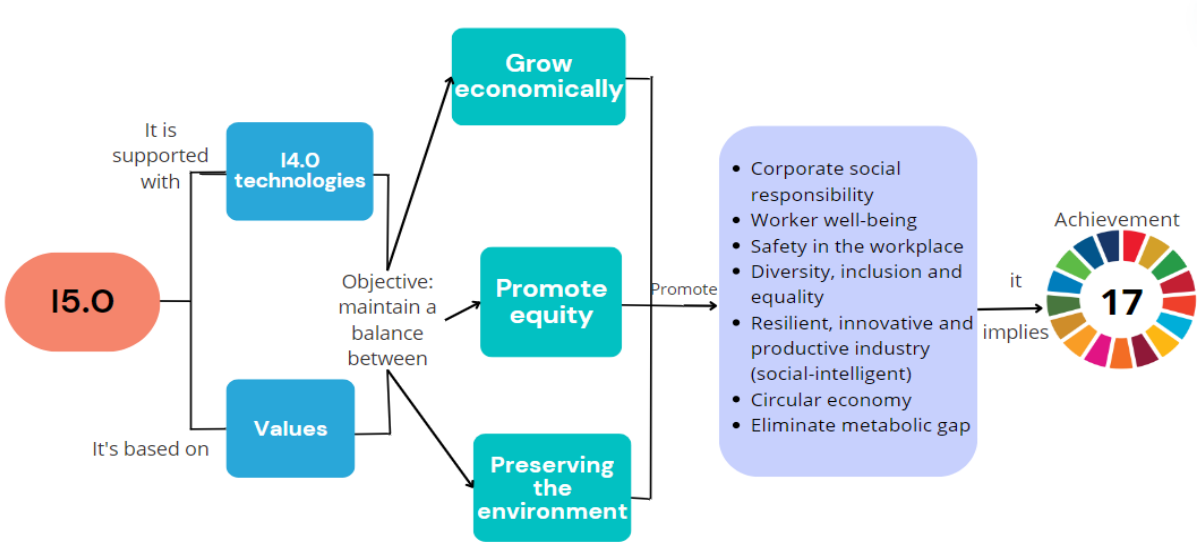


Figure 6 provides a diagram that helps to understand in greater depth the goal and implications of the emergence of I5.0, and how its correct application can lead to the achievement of the SDGs and the 2030 Agenda.

Figure 6. Industry 5.0 Scheme. Source: own elaboration.



6. Conclusions

While it's true that cost savings, improved management, and the current environmental and carbon footprint of industries through the use of digital enabling technologies present in Industry 4.0 could be enhanced, it is these very technologies that promise, in the near future, to be key in reducing emissions through improved energy efficiency. They also promise to increase well-being, comfort, safety, and other values associated with the Sustainable Development Goals.

In this context, adopting the concept of Industry 5.0 becomes absolutely necessary, promoting an industry that is responsible towards human well-being, the environment, and resilient in terms of the value chain.

Throughout this article, all the enabling technologies of Industry 4.0 have been analyzed as they are also available in Industry 5.0, reviewing existing literature and presenting the contributions of various authors.

The research has focused on Porter's value chain, workers, and the environment. From this, applying VSD, a sustainability sphere emerges that every current industry should strive to achieve in pursuit of the SDGs. This sustainability sphere is achieved through a balance between an economically profitable industry, equitable to humans, and beneficial to the environment.

It is concluded that the industry's roadmap must align with digital, green, and social transformation, and one of the main goals should be to increase the design, manufacturing, and use of net-zero emissions technologies, all supported under the principles of corporate social responsibility and contributing to achieving the values upon which Industry 5.0 and the SDGs of the 2030 Agenda are based.

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