

How Enterprise Systems Enable Sustainable Digital Transformation: An Evaluation of Industry 4.0 Practices and Risks in the Brazilian Context

LIMAD, W. G.N¹., SILVA, M.L.P²., SIGAHI, T.F.A.C³.

¹ Researcher, Laboratory of Integrable Systems (LSI), Department of Electrical Engineering, Polytechnic School, University of São Paulo (EPUSP), São Paulo, SP, Brazil. E-mail: wlimad@alumni.usp.br

² Professor, Paula Souza State Center for Technological Education (CEETEPS), São Paulo, SP, Brazil.

³ Associate Professor, Department of Production Engineering, Polytechnic School, University of São Paulo (EPUSP), São Paulo, SP, Brazil.



Published in
VOI- 2 Issue: 3

DOI:10.5281/zenodo.20258725

PP: 01-09

*Correspondence:

LIMAD, W. G.N

Researcher, Laboratory of
Integrable Systems (LSI),
Department of Electrical
Engineering, Polytechnic
School, University of São Paulo
(EPUSP), São Paulo, SP,
Brazil. E-mail:
wlimad@alumni.usp.br

Abstract

This paper presents the results of a study corresponding to Phase I of a broader research project on the Sustainable Adoption of Industry 4.0 (AS-I4) in the Brazilian context. The empirical focus is placed on the integration of Enterprise Resource Planning (ERP) systems and Artificial Intelligence (AI) applied to inbound logistics, particularly warehousing, picking operations, and decision-support processes. Methodologically, the study adopts an exploratory approach based on a structured literature review and a field survey conducted with academic and industry experts. The results indicate that ERP–AI integration is predominantly perceived as a driver of operational efficiency, productivity gains, cost reduction, and improved coordination of logistics processes. However, the findings also reveal the presence of significant socio-technical risks related to data governance, cybersecurity, system reliability, and workforce preparedness. The combined analysis highlights a structural tension between efficiency-oriented benefits and sustainability-related challenges, suggesting that Industry 4.0 adoption in logistics environments remains largely functional and instrumental, rather than strategically aligned with a comprehensive sustainability agenda. As a contribution, this study empirically frames the sustainable adoption of Industry 4.0 through the lens of ERP–AI-supported inbound logistics, reinforcing the need for integrated governance mechanisms that align technological capabilities, organizational processes, and human factors. The results provide an initial diagnostic foundation for subsequent research phases aimed at advancing AS-I4 maturity assessment and decision-support frameworks in logistics systems.

Index Terms: Industry 4.0, sustainability ERP, artificial intelligence, inbound logistics.

Introduction

The increasing incorporation of digital technologies into production systems has intensified academic and managerial debates surrounding Industry 4.0 and its organizational impacts [1], [2]. Technologies such as Cyber-Physical Systems, the Internet of Things, Big Data Analytics, and Artificial Intelligence are widely

associated with gains in efficiency, flexibility, and competitiveness. However, as these technologies diffuse across industrial sectors, it becomes increasingly relevant to understand how their adoption can occur in a sustainable manner, encompassing not only economic outcomes but also social, organizational, and environmental dimensions.

In the Brazilian context, the adoption of Industry 4.0 technologies presents specific challenges related to infrastructure limitations, workforce qualification, data governance, and organizational heterogeneity [3]–[5]. Empirical evidence suggests that, despite isolated advances, technological adoption tends to be fragmented and primarily driven by short-term operational gains. Within this scenario, the concept of Sustainable Adoption of Industry 4.0 (AS-I4) has emerged as an integrative perspective that aligns digital transformation with governance structures, human capabilities, and long-term strategic objectives [6] – [8].

Among the organizational domains affected by Industry 4.0, inbound logistics stands out as a strategic-operational area. The integration of ERP systems with AI-based solutions offers significant potential for flow optimization, information accuracy, and advanced decision support. Nevertheless, such integration also introduces socio-technical challenges that must be understood systematically.

Therefore, this paper aims to present and discuss the results of a preliminary study corresponding to Phase I of a broader research project on AS-I4 in Brazil. Specifically, it analyses expert perceptions regarding the contributions and risks associated with Industry 4.0 technologies applied to an ERP–AI-supported inbound logistics environment. This study serves as an exploratory diagnostic, providing empirical inputs for subsequent research phases.

I. THEORETICAL BACKGROUND

A. Industry 4.0 and Sustainability Correlations

Industry 4.0 is characterized by the integration of advanced digital technologies into production and logistics systems, enabling higher levels of connectivity, automation, and analytical capability [1], [9]. Although such technologies offer substantial benefits, prior studies highlight potential adverse effects, including increased organizational complexity, cybersecurity risks, and labour-related impacts.

In response, the concept of Sustainable Adoption of Industry 4.0 emphasizes the need to balance economic performance with social responsibility, organizational readiness, and environmental considerations [6], [10]. AS-I4 assumes that digital transformation should be accompanied by governance mechanisms, workforce development, and strategic alignment, avoiding isolated or purely technology-driven initiatives.

B. ERP and Artificial Intelligence in Logistics Environments

ERP systems play a central role in integrating organizational information and supporting planning and control processes [11]. In logistics environments, ERP systems are essential for managing inventories, orders, material flows, and information consistency.

The incorporation of AI solutions into ERP systems significantly expands their analytical capabilities by enabling predictive analyses, pattern recognition, and decision-support functionalities [12], [13]. In inbound logistics, AI applications may contribute to layout optimization, picking efficiency, inventory accuracy, and responsiveness to demand variability. However, these applications require high-quality data, adequate infrastructure, and skilled users, reinforcing the importance of a sustainable adoption perspective.

II. METHODOLOGY

This study adopts an exploratory research design, appropriate for investigating phenomena that are still insufficiently understood or in early stages of development [14]. The research comprises two main stages: complementary stages, illustrated in Figure 1. The first stage consists of a systematic literature review encompassing Industry 4.0, Advanced Smart-Industry 4.0 (AS-I4), Enterprise Resource Planning (ERP), and the application of artificial intelligence to logistics contexts. This foundation ensures that the field survey is grounded in current theoretical frameworks and evidence-based understanding of the research domain.

The second stage represents Phase I of the field research, employing a structured questionnaire administered to subject matter experts with demonstrated academic and professional experience across three specialized domains: Production Engineering, Sustainability, and Industry 4.0. The questionnaire was designed around two focused research questions: Question 1 assesses Industry 4.0's contributions across 16 sustainability-related dimensions using the framework proposed by Ghobakhloo [6], while Question 2 evaluates expert perceptions regarding the presence and severity of 10 distinct risk categories relevant to the Brazilian manufacturing context.

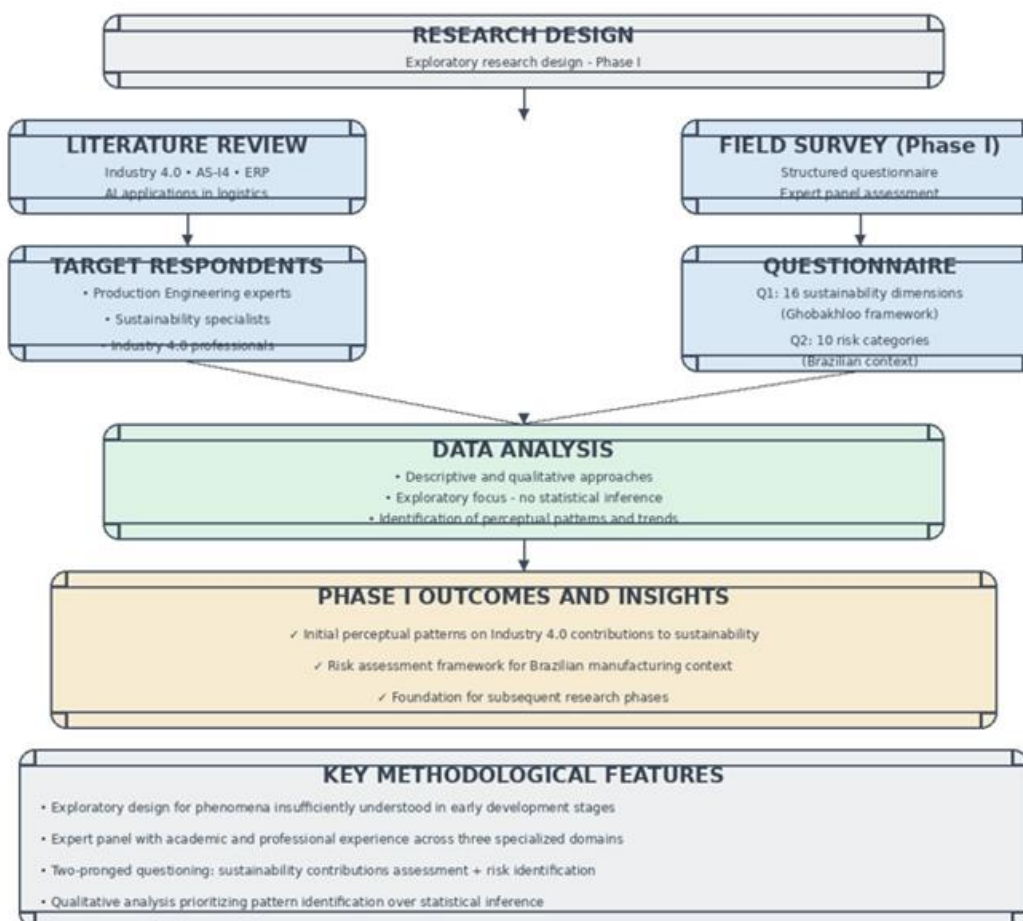


Figure 1 – Research methodology flowchart

Source: Prepared by the author (2026).

The field survey was conducted using a structured questionnaire administered to experts with academic and professional experience in Production Engineering, Sustainability, and Industry 4.0 [15].

The instrument consisted of two main sections: Question 1, based on the framework proposed by Ghobakhloo [6], assessing Industry 4.0 contributions across 16 sustainability-related dimensions; and Question 2, grounded in prior studies on Industry 4.0 risks, evaluating perceptions regarding the presence of 10 risk categories in the Brazilian context.

Data analysis followed approaches consistent with the exploratory nature of Phase I research [16], emphasizing descriptive and qualitative interpretation over statistical inference. Rather than seeking probabilistic generalizations or hypothesis testing, the analysis prioritized the identification of perceptual patterns, consensus points, and emerging trends among the expert cohort. These initial insights establish a foundation for interpreting literature-derived theories through the lens of practitioner experience, ultimately informing the design and focus of subsequent research phases. The combination of literature-grounded questioning, expert validation, and exploratory analysis creates a methodologically coherent pathway from theoretical frameworks to empirically informed research advancement.

III. RESULTS AND DISCUSSIONS

The results are presented and discussed in two stages, beginning with the characterization of the respondents and followed by the analysis of the perceptions obtained from Question 1.

A. Respondent Profile

Phase I included respondents with high academic and professional maturity, predominantly professors, researchers, and corporate managers, with professional experience ranging from approximately 15 to 30 years. This profile provides cognitive robustness to the sample and supports its use as an exploratory diagnostic basis.

Table I – Respondent Profile at Phase I

Category	Quantity	Percentage
Academics	11	68.75%
Industry Prof.	5	31.25%
Total	16	100.00%

A. Results of Question 1

From the specific perspective of the ERP–AI integration investigated in this study; the results of Question 1 reinforce that respondents primarily associate Industry 4.0 technologies with improvements in inbound logistics operations. The concentration of higher-scale responses in dimensions related to productivity, cost reduction, process speed, and supply chain integration reflects the perceived role of ERP–AI solutions as enablers of operational coordination, data accuracy, and analytical decision support in logistics environments.

Responses indicate a non-homogeneous perception of the use of Industry 4.0 technologies across the 16 sustainability-related dimensions. A clear concentration at the upper end of the scale (high and very high use) emerges in subdimensions linked to economic and operational performance, such as productivity, cost reduction, production flexibility, process speed, and supply chain integration. This pattern suggests that

respondents predominantly associate Industry 4.0 with efficiency gains and performance improvement, rather than with broader sustainability outcomes.

On the other hand, subdimensions related to social and organizational sustainability —such as employee development, sustainable business model innovation, job creation, and social well-being — exhibit a more dispersed distribution, with a higher presence of low and medium-scale responses. Although these dimensions are recognized as relevant, their practical integration into Industry 4.0 initiatives appears limited in the analysed context.

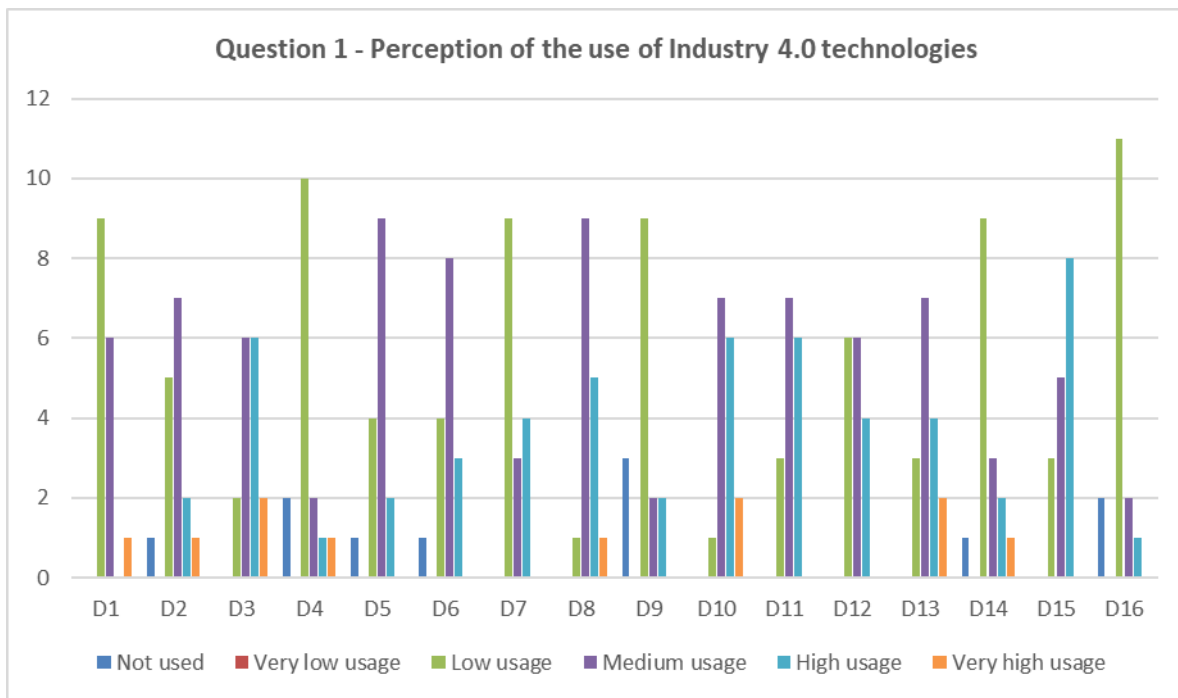


Fig. 1: Bar chart showing distribution of responses for D1–D16 across the 5-point scale
Source: Prepared by the author (2026).

Figure 1 presents the distribution of respondents’ perceptions regarding the use of Industry 4.0 technologies across sustainability-related dimensions (Question 1).

Note: The underlying tabulated data indicate that AI-enabled ERP modules are perceived as strong drivers of economic and operational sustainability. However, the relatively low scores observed in socio-environmental dimensions suggest that the potential of AI to enhance holistic sustainability remains underexplored, highlighting the need for further empirical research to strengthen this understanding and support strategic implementation.

Taken together, these results suggest that Industry 4.0 adoption in Brazil remains primarily functional and instrumental, driven by efficiency-oriented objectives rather than by a comprehensive sustainability strategy aligned with AS-I4 principles.

A. Results of Question 2

From the specific perspective of ERP–AI integration in inbound logistics, the risks identified in Question 2 assume a distinctly socio-technical character. The prominence of technological risks—particularly those related to digital security, data governance, and system reliability—reflects the increased dependence of logistics operations on integrated information systems and algorithmic decision-making. In

ERP–AI-supported logistics environments, disruptions, data inconsistencies, or cybersecurity breaches may propagate rapidly across planning, warehousing, and execution processes, amplifying operational vulnerability.

Responses indicate that the perceived risks associated with Industry 4.0 adoption are not uniformly distributed across categories. Higher concern is concentrated in technological aspects — particularly digital security, data privacy, ethical use of information, and technical vulnerabilities — suggesting that these issues are viewed as central challenges in digital transformation processes.

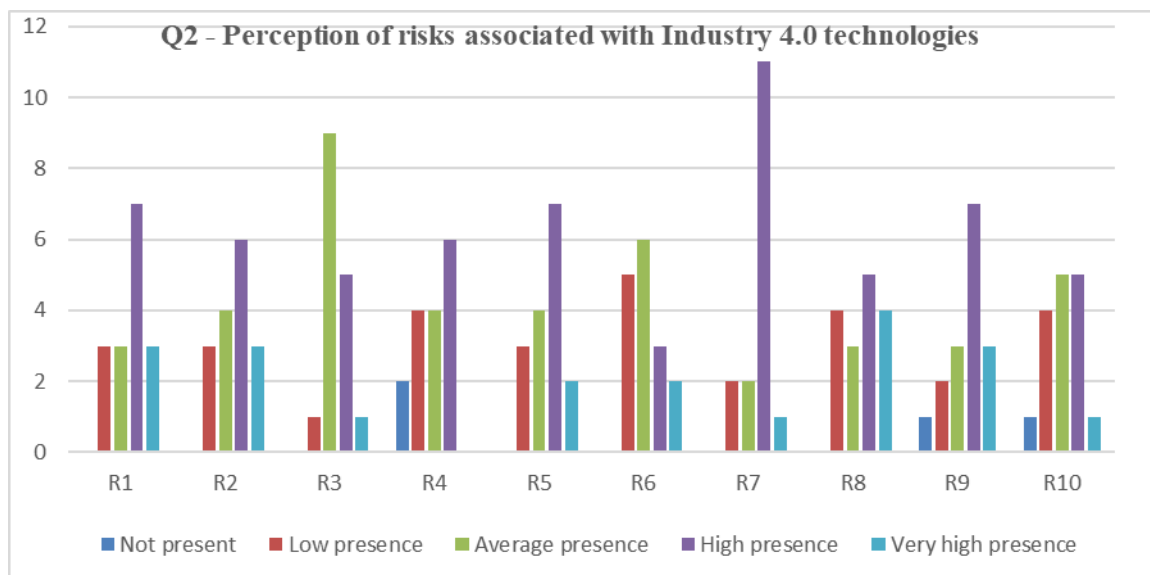


Fig. 2: Bar chart showing distribution of responses for R1–R10 across the 5-point scale
Source: Prepared by the author (2026).

Figure 2 presents respondents’ perceptions of the risks associated with the adoption of Industry 4.0 technologies (Question 2).

Note: The underlying data suggest that AI-driven logistics systems are associated with higher perceived risks, particularly in data governance and technical reliability. Although AI contributes to operational sustainability through predictive optimization and resource tracking, these concerns indicate that further interdisciplinary research is needed to address socio-technical vulnerabilities and strengthen its role as a reliable enabler of sustainability.

Environmental risks, such as increased energy consumption, disposal of obsolete technologies, and dependence on scarce resources, present an intermediate distribution, with responses mainly concentrated at medium and high levels. Social and economic risks, including workforce qualification gaps, structural unemployment, and impacts on small and medium-sized enterprises, show greater dispersion, reflecting uncertainties regarding their short- and medium-term materialization.

IV. DISCUSSION

The results of Phase I indicate that AS-I4 in the Brazilian context is currently perceived as an emerging but uneven process. The combined analysis of Questions 1 and 2 highlights a structural tension at the core of sustainable Industry 4.0 adoption in ERP–AI-supported inbound logistics environments. On the one hand, the results indicate that the integration of ERP systems and artificial intelligence is predominantly perceived as a driver of operational efficiency, productivity gains, cost reduction, and improved coordination

of logistics processes. On the other hand, this same integration intensifies technological and organizational risks related to data governance, system reliability, cybersecurity, and workforce preparedness.

From an AS-I4 perspective, these findings suggest that the sustainable adoption of Industry 4.0 technologies in logistics cannot be assessed solely through performance-oriented outcomes. The strong association between ERP–AI integration and operational benefits, as discussed in Section IV.B, is inseparable from the socio-technical vulnerabilities identified in Section IV.C. In highly integrated logistics systems, the dependence on centralized data structures and algorithmic decision-making amplifies both value creation potential and systemic exposure to disruptions.

This duality reinforces the argument that sustainable Industry 4.0 adoption in the Brazilian context remains at an intermediate stage of maturity. While organizations recognize the economic and operational value of ERP–AI integration, the management of associated socio-technical risks appears less developed. Consequently, AS-I4 in logistics environments requires governance mechanisms that explicitly address data quality, cybersecurity, human competencies, and organizational alignment, ensuring that efficiency gains do not undermine long-term sustainability objectives. Importantly, the data confirm that Artificial Intelligence holds significant potential to advance sustainability through predictive resource allocation, waste reduction, and transparent supply chain monitoring. However, this perception remains fragmented in practice, and further longitudinal and cross-sectoral studies are required to consolidate AI's role as a systemic sustainability driver rather than a purely instrumental efficiency tool.

V. CONCLUSION AND FUTURE WORK

This paper presented the results of a preliminary study on the sustainable adoption of Industry 4.0 technologies in the Brazilian context, with a specific empirical focus on the integration of Enterprise Resource Planning systems and Artificial Intelligence applied to inbound logistics. By adopting the perspective of Sustainable Adoption of Industry 4.0 (AS-I4), the study contributes to understanding how digital transformation unfolds beyond purely technological or performance-oriented considerations.

The findings of Phase I indicate that ERP–AI integration is predominantly perceived as a driver of operational efficiency, productivity gains, cost reduction, and improved coordination of logistics processes. These benefits reinforce the strategic relevance of integrated information systems and analytical technologies in inbound logistics environments. However, the results also demonstrate that such gains are accompanied by significant socio-technical risks, particularly related to data governance, cybersecurity, system reliability, and workforce preparedness.

The combined analysis of benefits and risks reveals a structural tension that characterizes the current stage of AS-I4 in the Brazilian logistics context. While organizations recognize the economic and operational value of ERP–AI integration, the management of associated social, organizational, and governance challenges remains less mature. This imbalance suggests that Industry 4.0 adoption in logistics environments is still predominantly functional and instrumental, rather than strategically aligned with a comprehensive sustainability agenda.

From a scientific perspective, the main contribution of this study lies in empirically framing the sustainable adoption of Industry 4.0 through the lens of ERP–AI-supported inbound logistics, highlighting the inseparability of efficiency gains and socio-technical vulnerabilities. By doing so, the paper advances the AS-I4 literature by emphasizing the need for integrated governance mechanisms that align technology, processes, and human capabilities in highly digitalized logistics systems. The evidence strongly indicates

that Artificial Intelligence can substantially improve sustainability metrics when embedded within structured ERP architectures. Nevertheless, this potential is not yet fully realized or widely perceived in emerging economies, highlighting the urgent need for expanded empirical research, standardized ESG-AI integration frameworks, and capacity-building initiatives.

As a preliminary investigation, this study is subject to inherent limitations, including its exploratory nature and the use of perceptual data from a restricted expert sample. Nevertheless, the results provide a robust diagnostic foundation for subsequent research phases. Future studies will deepen the analysis of AS-I4 barriers using multicriteria decision-making methods, examine interactions among technological, organizational, and social factors, and assess maturity levels of sustainable Industry 4.0 adoption in logistics environments.

In this sense, the present work fulfils its role as an initial empirical and conceptual step toward a research agenda focused on promoting a more balanced and sustainable digital transformation in ERP–AI-enabled logistics systems.

Funding and Acknowledgments:

The authors acknowledge the support of the Post-Doctoral Program of the Polytechnic School, University of São Paulo (EPUSP), and the Laboratory of Integrable Systems (LSI), and the Paula Souza State Center for Technological Education (CEETEPS).

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Author Contributions:

- ❖ Conceptualization: W.G.N. Limad, T.F.A.C. Sigahi
- ❖ Methodology: W.G.N. Limad, T.F.A.C. Sigahi, M.L.P. Silva
- ❖ Software / AIFC Development: W.G.N. Limad
- ❖ Formal Analysis: W.G.N. Limad, T.F.A.C. Sigahi, M.L.P. Silva
- ❖ Investigation / Data Curation: W.G.N. Limad
- ❖ Writing – Original Draft: W.G.N. Limad
- ❖ Writing – Review & Editing: W.G.N. Limad, T.F.A.C. Sigahi, M.L.P. Silva
- ❖ Supervision: T.F.A.C. Sigahi
- ❖ Project Administration: T.F.A.C. Sigahi

REFERENCES

1. M. Ghobakhloo, “The future of manufacturing industry: A strategic roadmap toward Industry 4.0,” *J. Manuf. Technol. Manag.*, vol. 29, no. 6, pp. 910–936, 2018, DOI: 10.1108/JMTM-02-2018-0057.
2. L. B. Furstenau et al., “Link between sustainability and Industry 4.0,” *IEEE Access*, vol. 8, pp. 140079–140096, 2020, DOI: 10.1109/ACCESS.2020.3012812.
3. J. M. Müller, D. Kiel, and K.-I. Voigt, “What drives the implementation of Industry 4.0? The role of opportunities and challenges in the context of sustainability,” *Sustainability*, vol. 10, no. 1, p. 247, 2018, DOI: 10.3390/su10010247.
4. G. L. Tortorella et al., “Organizational learning paths based upon Industry 4.0 adoption,” *Int. J. Prod. Econ.*, vol. 219, pp. 284–294, 2020, DOI: 10.1016/j.ijpe.2019.06.023.



5. P. F. S. Siltori et al., "Industry 4.0 and corporate sustainability: An exploratory study," *Technol. Forecast. Soc. Change*, vol. 167, p. 120741, 2021, DOI: 10.1016/j.techfore.2021.120741.
6. M. Ghobakhloo, "Industry 4.0, digitization, and opportunities for sustainability," *J. Clean. Prod.*, vol. 252, p. 119869, 2020, DOI: 10.1016/j.jclepro.2019.119869.
7. I. S. Khan et al., "Industry 4.0 and sustainable development: A systematic review," *J. Clean. Prod.*, vol. 297, p. 126655, 2021, DOI: 10.1016/j.jclepro.2021.126655.
8. T. C. Ng et al., "The application of Industry 4.0 technological constituents for sustainable manufacturing," *Sustainability*, vol. 14, no. 7, p. 4327, 2022, DOI: 10.3390/su14074327.
9. T. Stock et al., "Industry 4.0 as enabler for sustainable development: A qualitative analysis of sustainability potentials," *Process Saf. Environ. Prot.*, vol. 118, pp. 254–267, 2018, DOI: 10.1016/j.psep.2018.06.026.
10. A. M. Braccini and E. G. Margherita, "Exploring organizational sustainability of Industry 4.0," *Sustainability*, vol. 11, no. 1, p. 36, 2019, DOI: 10.3390/su11010036.
11. H. L. Corrêa, I. G. N. Giansesi, and M. Caon, *Production Planning and Control: MRP II and ERP*, 6th ed. Rio de Janeiro, Brazil: Atlas, 2018.
12. T. H. Davenport and R. Ronanki, "Artificial intelligence for the real world," *Harv. Bus. Rev.*, vol. 96, no. 1, pp. 108–116, 2018.
13. K. Faceli et al., *Artificial Intelligence: A Machine Learning Approach*, 2nd ed. Rio de Janeiro, Brazil: LTC, 2021.
14. A. C. Gil, *Methods and Techniques of Social Research*, 6th ed. São Paulo, Brazil: Atlas, 2008.
15. C. Forza, "Survey research in operations management: A process-based perspective," *Int. J. Oper. Prod. Manag.*, vol. 22, no. 2, pp. 152–194, 2002, DOI: 10.1108/01443570210417663.
16. R. K. Yin, *Case Study Research: Design and Methods*, 5th ed. Porto Alegre, Brazil: Bookman, 2015.

