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How can Industry 5.0 transform operational excellence into a driver to achieve SDGs in Ibero-American countries?

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Abstract

Purpose – The purpose of this study is to explore how operational excellence (OPEX) can be redefined in the era of Industry 5.0 (I5.0) by integrating human-centric, sustainability and resiliency principles. This study investigates the role of emerging technologies and I5.0 to align OPEX with the United Nations Sustainable Development Goals (SDGs) and highlights the involvement of multiple stakeholders in this transformation. This is particularly relevant for Ibero-American countries, where organisations are increasingly seeking to incorporate sustainability and human-centric values into their operational models to meet global development targets.

Design/methodology/approach – The authors adopted a conceptual and literature-based approach to review and synthesise academic literature and industry reports on OPEX, Industry 4.0 (I4.0) and I5.0. This study examines how cobots, digital twins, artificial intelligence and blockchain can be integrated with sustainability principles within OPEX systems and can be mapped to specific SDGs through a multi-stakeholder perspective.

Findings – This study finds that I5.0 shifted the OPEX from efficiency-focused to inclusive, resiliency and sustainability. OPEX in I5.0 supports SDG 8 (Decent Work), SDG 9 (Industry and Innovation), SDG 12 (Responsible Production), SDG 13 (Climate Action) and SDG 17 (Partnerships) by enabling human–machine collaboration and circular practices. This study emphasises that multi-stakeholder engagement is critical to achieve these outcomes. These findings hold strong potential to guide the ongoing OPEX transformations across Ibero-American organisations aiming to align with their global SDG benchmarks.

Practical implications – This study provides the guidelines to industries and policymakers on redesigning OPEX models to balance competitiveness with social and environmental responsibilities. This study offers the specific strategic directions that can support Ibero-American countries in incorporating I5.0 principles into their operational systems to support SDGs.

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Originality/value – This paper offers one of the initial structured discussions that integrates OPEX, I5.0 principles and SDGs into a single framework, which is shifting the theoretical view of OPEX from a firm-centric process capability to a multi-stakeholder sustainability enabler.

Keywords Operational excellence, Industry 5.0, Advanced technologies, Sustainable development goals, Lean 4.0, Leadership for OPEX

Paper type Research paper

1. Introduction

The rapid technological transformation is fundamentally reshaping how organisations create value, compete and contribute to society (Volti and Croissant, 2024). With the increased use of digital tools, digital transformation has become important for organisations to remain competitive in the global business environment. However, these changes are not limited to the businesses but also affect the environment, society and institutions (Kraus *et al.*, 2021). In regions such as Ibero-America, this transformation is particularly important, as organisations are under pressure to balance global competitiveness with social and environmental priorities (America and America, 2020). The region's ongoing digital transformation can offer a new opportunity to incorporate sustainability and human-centric principles within OPEX practices. As organisations adopt Industry 4.0 (I4.0), the idea of Industry 5.0 (I5.0) has also emerged, with a greater focus on resiliency, sustainability and human centricity (Xu *et al.*, 2021).

Digitalisation is seen as a strategy for organisations to gain an edge by improving operations. It supports lower costs, faster delivery, improved quality and customer satisfaction. These improvements contribute directly to achieving OPEX (Luz Tortorella *et al.*, 2022). OPEX is widely used in the business context, but its meaning is unclear because of its use as a goal rather than a clear concept (Found *et al.*, 2018). The term has a wide range of acceptability in manufacturing and service organisations, as it helps to boost productivity, reduce costs by improving quality and customer experience (Antony *et al.*, 2024). Therefore, OPEX-based projects are being implemented at the global level to achieve competitive advantage and long-term sustainability (Antony *et al.*, 2023). OPEX is about reliable strategy execution and long-term cultural transformation (Tortorella *et al.*, 2024). A recent study on the Colombian manufacturing sector emphasised that OPEX plays an important role in improving competitiveness and resource efficiency. The study also identified that micro, small and medium enterprises prioritise physical infrastructure, stakeholder engagement and area-specific applications of OPEX to overcome structural and capability-related challenges in their operations (Aguirre-Alvarez *et al.*, 2025).

Considering the present business scenario, it is found that advanced technologies can help to maximise output, resource optimisation and address manufacturing challenges more effectively than traditional methods. Therefore, manufacturers are integrating OPEX strategies with advanced technologies (Pansare *et al.*, 2022). A report from McKinsey discussed that OPEX today requires more than technology, as it depends on purpose, strategy, people and systems to create value. Companies that integrate these elements are likely to achieve higher productivity, resilience and growth [1]. Qeytasi *et al.* (2025) applied the Shingo model to bridge the transition from I4.0 to I5.0 and discussed how cultural enablers and human-centred values can strengthen OPEX. A recent empirical study examined the factors influencing I4.0 implementation and found that human factors and ergonomics play a mediating role to achieve OPEX (Virmani and Salve, 2021). A recent study in the oil and gas sector discussed how digitalised operational management systems

can significantly improve OPEX. The integration of data analytics and workflow automation improves decision-making, cost control and resource optimisation (Hegazy *et al.*, 2023).

The existing literature on OPEX discussed that it has been defined through the various practices such as Lean management (Ibrahim *et al.*, 2020), Six Sigma and continuous improvement approaches (Lameijer *et al.*, 2021). These primary objectives are related to cost reduction, quality improvement, efficiency improvement and process optimisation. Also, these approaches have transformed the industries by providing systematic methods for defect reduction, waste elimination and productivity improvement, which are the critical drivers for competitiveness (Gomaa, 2025a). However, in the digital era and transition towards I5.0, the scope of OPEX is undergoing a significant transformation (Hajjem *et al.*, 2025). Now it extends beyond the efficiency and also covers sustainability, resiliency and human-centric values. For instance, human–machine collaboration, which is enabled by cobots, helps to improve safety and productivity. It also allows workers to focus on value-added tasks, while automation handles repetitive operations (Rahman *et al.*, 2024). Digital twins enable predictive maintenance and real-time optimisation of the shop floor, which helps to minimise downtime and improve resource utilisation (Imandi *et al.*, 2025). Other technologies, such as blockchain, help to improve accountability, traceability and transparency across the supply chain (Verma *et al.*, 2022). Artificial intelligence (AI) is helping organisations to develop advanced decision support systems so that they can respond quickly to dynamic market demands (Martini *et al.*, 2024). In I5.0, OPEX is not limited to operational efficiency but also integrates sustainability, human well-being and adaptability for long-term value creation (Hajjem *et al.*, 2025).

OPEX is also aligned with the United Nations Sustainable Development Goals (SDGs), which extends its scope beyond efficiency and covers societal outcomes in I5.0 (Wojtkowiak and Cyplik, 2020). Generally, OPEX focuses on improving quality, efficiency and safety through lean and Six Sigma practices. In I5.0, which improves worker safety, upskilling addresses SDG8 (Pasman and Behie, 2024). Also, through innovation-driven infrastructure, it supports SDG9. As I5.0 is more focused on sustainability, it addresses SDG12 and SDG13 (Atiku *et al.*, 2024). The current research on I5.0 has focused on sustainability dimensions, building resilient and responsible industries. These contributions provide valuable insights into the potential of I5.0 towards technological and environmental aspects. Nonetheless, there is a significant lack of literature about the systematic integration between OPEX and SDGs in the context of I5.0. Existing studies are more focused on technological adoption and overlook OPEX principles, which can be redefined to drive sustainability and performance. For instance, Boumsisse *et al.* (2024a) explored how behavioural factors affect OPEX in I5.0 and proposed a model with practical guidance for implementation. Boumsisse *et al.* (2024b) discussed that integrating I5.0 technologies with Green-Lean Six Sigma improves sustainability through process optimisation, resource utilisation and driving eco-innovation. IoT boosts operational excellence (OPEX) in I5.0 through automation and predictive tools, though SMEs face adoption barriers that require modular solutions, standards and policy support (Silva-Atencio, 2025). Souza *et al.* (2025) developed a Toyota Kata-based framework to place workers at the centre of digital adoption in I5.0 to bridge a key gap in manufacturing practices. However, none of these studies offers insights into how I5.0-based technologies can help to achieve OPEX and how they can contribute towards SDGs. Therefore, to explore and understand this, the present study formulates the following research questions:

RQ1. How do the principles and technologies of I5.0 influence the advancement of OPEX practices towards achieving the SDGs?

RQ2. How does OPEX in I5.0 promote collaboration and shared value creation among multiple stakeholders?

RQ3. What strategic insights from literature can help organisations redesign OPEX practices to align with the human-centric, sustainable and resilient goals of I5.0?

To address the above-discussed research questions, this study adopts a qualitative and conceptual orientation, synthesising insights from academic literature, industry practices and policy frameworks that explore how the emerging I5.0 concept influences the design and implementation of OPEX systems to advance the SDGs. This study uniquely examines the transformation of OPEX within the paradigm of I5.0, focusing on the convergence of human-centric, sustainable and resilient principles with advanced digital technologies. Unlike prior research that often isolates technical or efficiency-driven aspects of OPEX, this study integrates multiple stakeholder perspectives, which include workers, managers, human resource teams, leadership, suppliers, customers, policymakers and government agencies, to provide a holistic view of this transformation.

This study moves beyond conventional operational discourse by addressing the social, ethical and environmental dimensions of this shift, aligning with SDGs such as decent work and economic growth (SDG 8), industry, innovation and infrastructure (SDG 9), responsible consumption and production (SDG 12) and climate action (SDG 13). Through this approach, this study offers a comprehensive perspective on the future of OPEX in the I5.0 era and provides strategic recommendations for its successful adoption and scaling at a global level.

2. Literature review

2.1 OPEX in Industry 4.0

OPEX involves the implementation of methods like Just-in-Time, Total Quality Management and Six Sigma. These practices help industries to reduce their waste and improve customer value (Miandar *et al.*, 2020). OPEX in I4.0 integrates traditional OPEX practices with I4.0 technologies to improve efficiency and productivity (Miandar *et al.*, 2020). This approach leverages digital tools such as artificial intelligence, Internet of Things and big data analytics to optimise processes and decision-making. The I4.0 technologies have provided the structured frameworks for manufacturing organisations to remain competitive in the global market (Dalenogare *et al.*, 2018). Recent studies also discussed that the OPEX in I4.0, as the convergence of traditional excellence models with the digital technologies, help to develop more intelligent and data-driven approaches to performance management (Chiarini and Kumar, 2021).

Digital technologies such as IoT-based sensors, digital twins help to enable predictive maintenance and process visibility, which reduces downtime and improves efficiency (Panyaram, 2024). Similarly, the integration of artificial intelligence and big data analytics enables advanced quality management and allows manufacturing firms to predict errors and detect patterns (Paramesha *et al.*, 2024). With the help of advanced technologies, manufacturers can connect suppliers, manufacturers and customers to achieve end-to-end visibility and collaboration, which helps to improve responsiveness to market fluctuations (Ivanov, 2021). Few studies also highlighted that OPEX in I4.0 also contribute to sustainability goals by reducing waste and optimising energy consumption (Joshi *et al.*, 2024). The literature suggests that OPEX in I4.0 represents a paradigm shift, wherein efficiency is no longer pursued in isolation but is enhanced by digital technologies that ensure agility, resilience and sustainability. In I4.0, OPEX integrates Lean manufacturing, Six Sigma and Kaizen with advanced digital technologies to enhance productivity and quality (Gomaa, 2025b). Real-time data from sensors and analytics enables waste

elimination, defect reduction and continuous process improvement (Clancy *et al.*, 2023). This synergy helps in agile, efficient and data-driven operations that drive competitiveness. It signifies both an evolution of traditional OPEX practices and a foundation for I5.0, where human-centricity and broader societal objectives become integral to operational strategies. Figure 1 shows the three pillars of OPEX.

OPEX is built on a few key components, which ensure sustained performance and adaptability (Naik *et al.*, 2024). These include cultural enablers that promote employee engagement, continuous improvement practices that drive innovation and enterprise alignment that unites strategy with execution. These components create a structured framework to achieve consistent, high-quality results. The general components of OPEX are shown in Table 1.

2.2 OPEX in Industry 5.0

The shift from I4.0 towards I5.0 has redefined the scope of OPEX and transformed beyond efficiency and digitalisation towards human centricity, resilience and sustainability (Souza *et al.*, 2025). Recent studies highlighted that I5.0 is not the replacement for I4.0 but a complementary paradigm to achieve long-term societal well-being with technological advancements (Xu *et al.*, 2021). In this context, OPEX in I5.0 covers a broader scope where the traditional focus on cost, quality and speed is integrated with sustainable industry practices, ethical responsibility and human creativity (Boumsisse *et al.*, 2024c). OPEX in I5.0 is also continuing to leverage advanced technologies such as blockchain, digital twin and cobots, but their application is to support inclusivity and sustainability (Silva-Atencio, 2025). For example, cobots are no longer seen for productivity improvement but also for improving workplace safety and allow human workers to focus on innovation. Digital twins and predictive analytics improve resilience by enabling industries to simulate disruptions,

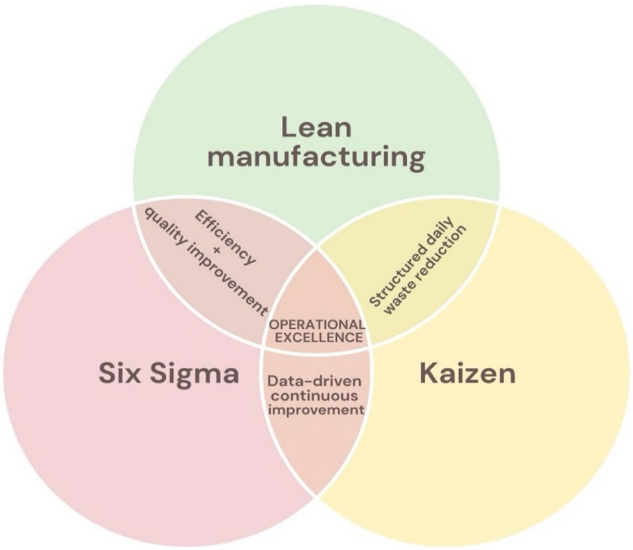

Figure 1. Three pillars of operational excellence
Source: Authors' own work

Table 1. Components of OPEX*

Component	Brief description	Reference
Customer focus	Customer focus is one of the components of OPEX, which emphasises the delivery of value through quality products, responsive services and reliable performance	Van Assen (2018)
Continuous improvement	Continuous improvement promotes the culture of ongoing enhancement in processes, products and services. It encourages iterative problem-solving, innovation and feedback integration, which enable organisations to respond swiftly to technological and market changes	Scavarda *et al.* (2025)
Standardization	Standardisation ensures uniformity in processes and quality practices across the organisation	Carvalho *et al.* (2023)
Efficiency and waste reduction	Efficiency and waste reduction focus on eliminating non-value-adding activities, optimising resource use and streamlining workflows	Siefan *et al.* (2025)
Employee engagement and empowerment	Employee engagement and empowerment are essential to sustaining OPEX. This component involves promoting ownership, collaboration and accountability among employees	Antony *et al* (2023a)
Data-driven decision-making	Data-driven decision-making integrates real-time operational data, advanced analytics and performance metrics to enhance decision quality	Rejikumar *et al.* (2020)
Strategic alignment	Strategic alignment ensures that operational activities and initiatives are closely connected to organisational vision, mission and long-term objectives	Ozbiltekin-Pala *et al.* (2024)

Source(s): * Authors' own work

optimise processes in real time and prepare adaptive strategies for dynamic market environments (Celestin, 2023).

Blockchain technologies help to strengthen the accountability and transparency in the supply chain to ensure ethical sourcing and trust among stakeholders (Oriekhoe *et al.*, 2024). Through the waste elimination and continuous improvement, OPEX in I5.0 supports SDG8 through workplace safety, decent employment and skill development. The integration of digital innovation promotes SDG9, in which resilient infrastructure and competitiveness are the outcomes. Through the principles of circular economy, OPEX in I5.0 contributes to SDG 12 on responsible consumption and production. Focusing on cooperation between industries, policymakers and communities directly connects with SDG 17 (Ambhore, 2024). This highlights the multi-stakeholder aspect of OPEX in the present context. The existing literature discusses OPEX in I5.0 as the strategic enabler for sustainable and inclusive growth, as it moves beyond the traditional efficiency goals to integrate resiliency, ethical practices and societal well-being (Hajjem *et al.*, 2025).

The OPEX in I5.0 not only aims to ensure efficiency and productivity but also addresses resiliency, sustainability and human centricity issues with the organisation system. It is more focused on adaptability and innovation, which can help the organisations to respond quickly to the societal and technological changes (Boumsisse *et al.*, 2024c). It adopts an integrated framework, which combines lean and agile practices with advanced digital technologies, which help to promote collaboration between machines and humans (Xu *et al.*, 2021). Because of the rising environmental concerns, sustainability has become important in global operations (Naik *et al.*, 2024). OPEX in I5.0 aims to support green supply chains, circular

economy models and carbon-neutral operations. This shift positions OPEX not only as the driver of competitiveness but also in terms of long-term environmental and social responsibility (Boumsisse *et al.*, 2024a). It integrates the efficiency-oriented approaches with the knowledge-driven strategies that combine process optimisation with innovation to prepare for a complex and technology-driven future. The goal of OPEX in I5.0 is to develop socially responsible and performance-driven organisations (Puneetha *et al.*, 2025). Linking operational performance with human creativity, digital intelligence and sustainability will help organisations to survive in dynamic and complex market environments (Puneetha *et al.*, 2025). Further, the guiding principles of OPEX and the role of I5.0 are shown in Table 2, which is based on Edgeman (2018*a*) and the Shingo Model [2].

3. Operational excellence in I5.0 towards sustainable development goals across stakeholders

The present section discusses how OPEX has been transformed in the digital age and addresses SDGs. The focus is on how OPEX practices can improve adaptability, efficiency and sustainability while engaging with multiple stakeholders. In the I4.0 context, OPEX is

Table 2. Guiding principles of operational excellence*

Principle category	Shingo guiding principles	Description	Role of Industry 5.0
Cultural enablers	Lead with humility, respect every individual	Build a culture where leaders are servant-mentors, and all individuals are valued as contributors	Artificial intelligence (AI) driven feedback systems can gather employee insights, implement to monitor well-being and use collaborative tools to remove unsafe tasks, ensuring dignity, inclusion and psychological safety
Continuous improvement	Embrace scientific thinking, focus on process, assure quality at source, seek perfection	Embed a mindset of experimentation, root-cause analysis and daily problem-solving at all levels	Apply for predictive maintenance, for virtual process simulations and Internet of Things (IoT) sensors for real-time quality monitoring to drive iterative improvements and zero-defect goals
Enterprise alignment	Create constancy of purpose, think systemically, create unity of purpose	Align all departments, suppliers and partners to shared long-term objectives	Use for transparent supply chain data sharing, for shared key performance indicators (KPI) dashboards and AI-driven strategy platforms to synchronise cross-functional and cross-enterprise priorities
Results	Create value for customers and stakeholders	Deliver consistent value in terms of quality, cost, speed, sustainability and social impact	Use sustainability analytics to track carbon footprints, AI-enabled demand forecasting to improve delivery performance and smart manufacturing for customised, sustainable and ethical products, supporting SDGs 8, 9, 12 and 13

Source(s): * Authors' own work

driven by digital transformation and process efficiency (Miandar *et al.*, 2020). Lean, Six Sigma and agile approaches are combined with advanced technologies to reduce waste and improve productivity. These practices help organisations to optimise their operations, resource utilisation and enable data-driven decision-making to improve market competitiveness (Chiarini and Kumar, 2021). In I5.0, there is a shift from efficiency-centric to human-centric and value-driven. This new era emphasises collaboration between humans and machines, resiliency against disruption and ensuring sustainability (Boumsisse *et al.*, 2024a). The focus is beyond productivity and includes social responsibility and ethical practices, which can contribute to long-term well-being (Chabane *et al.*, 2023). It also provides benefits in terms of operational resiliency, less environmental footprints, stakeholder trust and innovation-driven growth in an organisation. These outcomes support SDGs such as responsible consumption and production (SDG12), climate action (SDG13) and decent work and economic growth (SDG8).

Boumsisse *et al.* (2024b) discussed that I5.0 OPEX emphasises the integration of advanced technologies, such as intelligent automation and data analytics, with Green Lean Six Sigma practices to enhance sustainability and efficiency in manufacturing.

OPEX affects both internal and external stakeholders, with success relying on how firms engage employees, supply chains, customers and communities (Sony, 2019). Stakeholders play a crucial role in achieving OPEX by ensuring that their needs are identified and aligned with the organisation's capabilities (Bowden, 2000). They also influence and shape the enterprise's culture, processes and strategic direction (Edgeman, 2018b).

Studying stakeholder perspectives is important, as they provide insights into the complex relationships and interactions among various stakeholders involved in the value creation (Barney and Harrison, 2020). Therefore, it is important to study the stakeholders' perspectives for OPEX, as it broadens the definition of process improvement beyond mere cost and time reductions (Matthews *et al.*, 2019). There are various stakeholders involved in OPEX, including employees, management, regulators, suppliers and customers. These stakeholders have diverse requirements that organisations must address through integrated management systems (Asif *et al.*, 2010). Broadly, stakeholders can be categorised into internal or external stakeholders (Afum *et al.*, 2024).

3.1 Internal stakeholders in OPEX

Internal stakeholders play an important role in achieving OPEX within the supply chain (Mangla *et al.*, 2020a). They provide support to one another and ensure effective communication and coordination in business (Sirgy, 2002). Also, they promote employee involvement along with management commitment and involvement, which significantly influences the implementation of OPEX in manufacturing organisations (Antony *et al.*, 2023). But managerial thinking should shift from isolated operational improvements to long-term capacity building, which involves the involvement of internal stakeholders. By promoting collaboration and leveraging the unique skills and insights of these stakeholders, organisations can improve their competitiveness and effectively implement the micro-foundation of OPEX (Sunder M and Linderman, 2024). The list of internal stakeholders in OPEX is shown in Table 3.

3.2 External stakeholders in OPEX

At the present time, there is a need to rethink OPEX with an Organisational Ambidexterity framework. The long-term success requires both operational efficiency and innovation [3]. External stakeholders play a crucial role in OPEX by influencing the management of paradoxes that organisations face, particularly in the context of organisational ambidexterity

Table 3. Internal stakeholders in OPEX*

Internal stakeholder	Description	References
Worker	Workers play a crucial role as they contribute to enterprise culture and processes which influence the effectiveness of excellence models, particularly within continuous improvement systems. Middle managers can play an important role in promoting a work environment that enhances employee involvement	Edgeman (2018) and Lleo *et al.* (2017)
Managers	Managers also play an important role in implementing OPEX models. Their involvement is essential to provide strategic and visionary leadership, which ensures adequate resources and promotes a supportive organisational culture	Trakulsunti *et al.* (2023)
Human resource teams	The role of human resources (HR) in OPEX is to deliver high-quality HR services that align with business needs. Effective process management leverages HR to align workforce capabilities with the strategic objectives, which improves organisational competitiveness	Artis *et al.* (1999) and Kahveci *et al.* (2024)
Leadership	Effective management leadership is crucial to achieving OPEX in entrepreneurial organisations. It involves nurturing a culture of trust, respect and commitment among employees, which facilitates constant innovation	Darling *et al.* (2007)

Source(s): * Authors' own work

(Venugopal and Donnelly, 2025). External stakeholders also play an important role in achieving OPEX by challenging conventional sales and operations planning processes that are often internally focused. Their involvement encourages organisations to overcome structural rigidity and old routines, helping them drive innovation and change (Roscoe *et al.*, 2020). They also drive and facilitate sustainable supply chain management practices. Government and non-governmental organisations are key drivers which support the implementation of these practices (Siems *et al.*, 2023). External stakeholders also enhance business competitiveness through collaborative relationships and assist in developing sustainable innovations (Camilleri *et al.*, 2023). The list of external stakeholders in OPEX is shown in Table 4.

3.3 Role of digital technologies in driving OPEX towards SDGs from a multi-stakeholder perspective

Digital technologies have the potential to improve OPEX by transforming processes, enabling real-time data analytics and facilitating decision-making. These technologies support integration across operations, promote new business models and improve efficiency. It helps to improve organisational performance and provide a competitive advantage (Angelopoulos *et al.*, 2023). In this context, Buer *et al.* (2021) discussed how manufacturers can leverage digital technologies to improve operational performance. These technologies complement lean manufacturing practices and improve productivity within the organisations. From the supply chain context, these technologies' help to improve operational performance. Therefore, business should strategically align their supply chain management processes with digital technologies to navigate market complexities (Abi Anwar *et al.*, 2024). OPEX enhance sustainable development by integrating modern concepts, strategies and tools that promote social, environmental and corporate responsibility

Table 4. External stakeholders in OPEX*

External stakeholder	Description	References
Suppliers	Supplier relations are one of the influential critical success factors to implement OPEX initiatives in organisations. Effective collaboration and communication with suppliers help to enhance the overall performance of OPEX projects and contribute towards sustainability and competitive advantage	Mangla *et al.* (2020b)
Customers	Customer engagement plays a critical role in improving OPEX. By leveraging data to improve demand forecasting accuracy, firms can optimise inventory management strategies, which helps to reduce operational costs	Kovilage *et al.* (2022)
Policymakers	Policymakers play a crucial role in achieving OPEX by creating a conducive environment for the implementation of operations research strategies. By prioritising informed public policy choices and recognising the potential conflict among policy imperatives, they can facilitate strategic adaptation and evolution. It will help to improve the effectiveness of strategies to meet social goals	Korukonda (2006)
Government	The government plays an important role in enhancing firm-level operational efficiency in emerging economies. By effectively collecting and disseminating economic information, governments facilitate better decision-making for private firms, particularly in weaker information environments	Hope *et al.* (2022)

Source(s): * Authors' own work

(Wojtkowiak and Cyplik, 2020). By integrating efficiency and effectiveness in processes, waste reduction and promoting resource optimisation, it helps to achieve SDGs. This helps to promote long-term sustainability and enable organisations to achieve strategic sustainability objectives while maintaining high operational standards (Roche and Baumgartner, 2024). It integrates economic, social and environmental objectives by using methodologies like the Shingo model and Lean thinking. This helps to promote a continuous improvement culture and enable organisations to improve their performance across all sustainability pillars (Sá *et al.*, 2022).

3.4 Multi-stakeholder perspective

OPEX in I5.0 is transforming the core elements of operations, processes, workforce, infrastructure and leadership through the intelligent systems across the value chain (Hajjem *et al.*, 2025). For instance, AI is helping organisations to optimise their processes, improve decision-making and enable predictive analytics. It is driving performance improvements in manufacturing organisations (Dubey *et al.*, 2020). It is also automating routine tasks, which improves decision-making and reduces errors and better resource allocation (Spring *et al.*, 2022). Through the use of immersive visualisation, it improves human cyber-physical system connectivity and enables real-time monitoring and decision support in supply chain management (Tsang *et al.*, 2022). Blockchain technology helps to enhance information sharing and ensure real-time monitoring, which provides transparency and traceability throughout Lean Six Sigma projects (Rathi *et al.*, 2024). Digital twins enhance OPEX by enabling high-tech companies to analyse and visualise data, leading to improved efficiency

(Korepin *et al.*, 2025). Internal stakeholders can monitor real-time data, analyse operations and make informed decision, which also help to improve collaboration among engineers and designers. It helps to improve efficiency, reduce cost and quicker response time (Choi *et al.*, 2022). Robotics minimises human intervention and enhances efficiency in production processes, which enables stakeholders to respond swiftly to changes in production capacity (Gupta *et al.*, 2022). It automates processes, reduces variations in service delivery and enables high volumes of identical transactions. This minimises customer-induced variability, which allows organisations to achieve cost-effective excellence while maintaining high productivity and customer satisfaction (Wirtz *et al.*, 2023). The use of IoT improves OPEX by enabling real-time data collection and analysis, facilitating improved decision-making and optimising processes. This supports the implementation of circular economy practices, which lead to better operational performance and environmental sustainability in manufacturing firms (Prashar and Chaudhuri, 2025). IoT helps stakeholders to achieve OPEX by automating and digitalising supply chain processes, enhancing real-time monitoring of shipments and improving asset management through technologies like Global Positioning System (GPS), Near Field Communication (NFC) and Radio Frequency Identification (RFID) (Taj *et al.*, 2023). Big data analytics (BDA) enhances OPEX through innovative green product development and sustainable supply chain outcomes. It supports organisational learning and employee development, enabling stakeholders to leverage data for better decision-making and performance (Bag *et al.*, 2020). It provides insights that optimise processes, improve decision-making and increase efficiency. It supports the implementation of circular economy practices, which lead to better operational performance (Prashar and Chaudhuri, 2025). Augmented reality (AR) enhances process innovativeness, which in turn positively impacts operational performance. By facilitating innovative processes, AR helps stakeholders improve efficiency, reduce errors and optimise workflows (Turkcan *et al.*, 2023). It improves task accuracy, promotes collaboration and mitigating misinformation. This integration leads to better training outcomes and bridges theoretical knowledge with practical experience (Akinradewo *et al.*, 2024). Virtual reality (VR) enables stakeholders to simulate hazardous work conditions safely and enhance cognitive skills like problem-solving and decision-making. This training approach improves performance, reduces human error and provides valuable feedback for continuous improvement (Tichon, 2007). Table 5 shows the role of I5.0 to achieve OPEX across various stakeholders. Table 6 shows comprehensive overview of Shingo Guiding Principles for OPEX in I5.0 across stakeholders.

4. Discussion

This discussion section critically examines how OPEX practices within the framework of I5.0 are reshaping operational systems, stakeholder roles and sustainability outcomes. In this section, we have addressed the individual research questions discussed in the Introduction section.

RQ1. How do the principles and technologies of I5.0 influence the advancement of OPEX practices towards achieving the SDGs?

I5.0 represents a new revolution in industries that is more focused on human centricity, sustainability and resiliency, reshaping the OPEX practices (Boumsisse *et al.*, 2024c). In the earlier revolution, OPEX is more focused on defect reduction and efficiency. However, in I5.0, advanced technologies are integrated with human creativity and decision-making which can help organisations to achieve OPEX (Hajjem *et al.*, 2025), while addressing multiple SDGs such as SDG 8 (Decent Work), SDG 9 (Industry, Innovation and Infrastructure), SDG

Table 5. Role of I5.0 to achieve OPEX across various stakeholders*

OPEX components	Workers	Managers	Human resource teams	Leadership	Suppliers	Customers	Policymakers	Government
Customer focus	Can use IoT-enabled feedback tools and AR interfaces to tailor tasks to customer specs, which will improve responsiveness	Can apply AI-driven demand sensing to align production plans with changing customer preferences	Can design (AR)/(VR)-based customer empathy training to build service orientation	Can integrate customer-centric KPIs on real-time dashboards and link them with strategic goals	Can integrate digital collaboration platforms to share live design changes and delivery updates for better coordination	Can co-create products and offer sustainability feedback using digital engagement portals	Can frame digital consumer protection and ethical data-sharing policies for smart products	Can establish regulatory frameworks for real-time quality monitoring and safety certifications
Continuous improvement	Can use mobile Kaizen platforms and cobots to reduce repetitive errors and suggest improvements in real time	Can employ (ML) analytics to validate and monitor process changes	Can create micro-learning modules and gamified platforms to encourage skill-building and experimentation	Can set up innovation labs and allocate resources for cross-functional improvement projects	Can join joint Kaizen events using cloud-based platforms to address quality gaps	Can contribute product usage data through IoT-linked apps to inform design improvements	Can provide testbeds and sandbox environments to encourage continuous improvement initiatives	Can fund R&D clusters and public–private innovation networks to promote iterative improvement
Standardization	Can follow AR-based SOPs and wearable guidance systems to ensure consistent task execution	Can monitor conformance using systems and IoT sensors for real-time inspections	Can design digital certification systems to align workforce skills with standardised workflows	Can enforce global process standards combining quality, safety, and sustainability parameters	Can use blockchain-enabled digital passports to verify quality compliance	Can experience consistent quality and safety across product lines	Can develop interoperability and data-sharing protocols to unify standards	Can mandate international organisation for standardisation (ISO)-aligned smart quality systems across industries
Efficiency and waste reduction	Can collaborate with robots to minimise handling waste and use energy-monitoring wearables to cut idle time	Can optimise energy and material flow using AI-driven energy dashboards and manufacturing execution system (MES)	Can provide training on circular production, lean practices, and green logistics	Can invest in zero-defect and low-emission smart manufacturing systems	Can apply IoT route optimisation and digital packaging design to reduce material waste	Can access durable and low-impact products at lower lifecycle cost	Can create incentive policies for green manufacturing and energy efficiency	Can enforce MRV (monitoring–reporting–verification)-based regulations on emissions and waste

(*continued*)

Table 5. Continued

OPEX components	Workers	Managers	Human resource teams	Leadership	Suppliers	Customers	Policymakers	Government
Employee engagement and empowerment	Can engage in collaborative teams using digital platforms and AI chatbots for real-time support	Can use sentiment and engagement analytics dashboards to redesign work environments	Can deploy emotional-AI and ergonomics analytics to personalise learning and well-being programs	Can create inclusive, participative decision-making frameworks supported by digital feedback tools	Can run joint capability-building workshops to transfer knowledge and best practices	Can receive better service from motivated and empowered frontline employees	Can include decent work and inclusion metrics in industry codes of conduct	Can support large-scale reskilling and apprenticeship programs aligned with I5.0
Data-driven decision-making	Can track personal performance through IoT wearables and digital productivity dashboards	Can use big-data platforms and predictive analytics to optimise scheduling and resource planning	Can use workforce analytics to predict skills gaps and guide targeted upskilling efforts	Can embed operational, financial, and sustainability metrics into real-time strategy dashboards	Can share logistics and process data via APIs to support collaborative planning	Can access real-time order status, product traceability, and carbon impact details	Can define industrial data governance and cybersecurity frameworks	Can build national industrial data spaces and benchmarking platforms
Strategic alignment	Can understand organisational purpose through AR-based line-of-sight briefings connecting tasks to strategy	Can use balanced scorecard (BSC) and objectives and key results (OKRs) systems to cascade strategic goals	Can align workforce planning and competency frameworks with digital and sustainability roadmaps	Can publish long-term strategic targets on resilience, sustainability and human-centric growth	Can align capacity and sales and operations plans using shared planning portals and control towers	Can see consistent brand values and sustainability commitments across all channels	Can promote public–private partnerships linking operational excellence to societal goals	Can integrate OPEX principles into national I5.0 roadmaps and funding missions

Source(s): * Authors' own work

Table 6. Comprehensive overview of Shingo guiding principles for OPEX in I5.0 across stakeholders*

Shingo principles	Workers	Managers	HR teams	Leadership	Suppliers	Customers	Policymakers	Government
Lead with humility; respect every individual	Workers can log ideas and safety concerns via mobile, and use cobots to remove hazardous repetitive tasks	Managers can conduct digital gemba walks, act on ergonomics/ engagement dashboards and rebalance workloads with analytics	HR teams can deliver AR/VR micro-learning and improve skills while safeguarding data privacy	Leadership can fund accessible tooling for diverse talent	Suppliers can co-design safe work methods and share best practices on secure portals	Customers can join usability tests so that products respect diverse needs and contexts	Policymakers can issue guidance on worker voice, ergonomics and safe human–robot collaboration	Governments can enforce OSH standards with data-enabled inspections and co-fund national upskilling programs
Embrace scientific thinking; focus on process; assure quality at source; seek perfection *(Continuous improvement)*	Workers can run PDCA with e-Andon, use station-level SPC/ self-inspection, and submit Kaizen via mobile tools	Managers can test changes in digital twins, verify gains with SPC/ML dashboards and standardise proven practices	HR teams can provide adaptive e-learning on problem-solving/lean and allocate protected Kaizen time	Leadership can sponsor cross-functional improvement labs combining AI, robotics, and process experts; reward learning from experiments	Suppliers can join joint kaizen, deploy poka-yoke upstream, and share real-time quality data via APIs (or blockchain, where traceability is needed)	Customers can provide field/usage data and join beta programs to accelerate defect prevention	Policymakers can enable sector testbeds and benchmarking networks for SMEs	Governments can fund innovation hubs and streamline digital conformity assessment for quality-at-source
Create constancy of purpose; think systemically; create Unity of purpose *(Enterprise alignment)*	Workers can view AR "line-of-sight" briefings linking tasks to strategy and escalate misalignments quickly	Managers can Cascade OKRs, model system trade-offs with simulation, and synchronise plans across sites and partners	HR teams can align capability frameworks to strategy (green and digital skills) and plan mobility for roadmap milestones	Leadership can publish long-term targets (safety, OEE, lead time, CO_2) and align incentives to integrated KPIs	Suppliers can align S&OP, share capacity/ time fences and connect via shared planning portals for end-to-end flow	Customers can join roadmap councils and view transparent service/quality/ sustainability scorecards	Policymakers can foster interoperability standards and PPPs that align industrial and societal goals	Governments can publish Industry 5.0 roadmaps and targeted incentives for resilient, low-carbon supply networks
Create value for customers and stakeholders *(Results)*	Workers can use MES/IoT guidance to meet takt, assure quality at source, and suggest value-adding improvements	Managers can balance cost–service–carbon with analytics, manage risk, and improve OTIF reliability	HR teams can track engagement, safety, and inclusion metrics to sustain performance and well-being	Leadership can adopt integrated reporting, invest in circular models, and allocate value fairly across stakeholders	Suppliers can offer eco-design options and verified provenance via product/quality passports	Customers can receive reliable, customizable, lower-impact products with transparent origins	Policymakers can advance frameworks for product passports, eco-labels, and extended producer responsibility	Governments can implement MRV schemes for emissions and support green logistics infrastructure and digital compliance

Note(s) OEE = Overall Equipment Effectiveness, OKR = Objectives and Key Results, OSH = Occupational Safety and Health, OTIF = On Time In Full, PDCA = Plan–Do–Check–Act, S&OP = Sales and Operations Planning, SPC = Statistical Process Control, PPP = Public–Private Partnership and MRV = Monitoring, Reporting and Verification

Source(s): * Authors' own work

12 (Responsible Production and Consumption), SDG 13 (Climate Action), SDG 16 (Strong Institutions) and SDG 17 (Partnerships). The advanced technologies like AI and ML can help to enable predictive maintenance, real-time process optimisation and demand forecasting, which allows managers to react proactively (Kagalwala *et al.*, 2025). It will help to address potential failures and balance production with customer demands. Deep learning-based anomaly detection and Statistical Process Control (SPC) can support zero-defect production systems (Escobar *et al.*, 2025), which can help to reduce resource consumption as well as emissions and contribute to SDG 9, SDG 12 and SDG 13. For workers, these tools will provide guided decision support and reduce repetitive tasks, while top leadership can use aggregated data to make evidence-based strategic choices. Digital twin can create the virtual replicas of plans and supply chain, which enable managers to test different scenarios before implementation (Ivanov and Dolgui, 2021). This approach will help to improve resiliency and align with SDG 17 (Partnerships) through collaborative planning with suppliers. IoT and edge computing will be helpful to track the equipment status and energy usage, which ensures faster response to process deviations (Zhao *et al.*, 2020) and reinforces SDG 12 and SDG 13 through reduced scrap and optimised energy consumption. More focused on human–robot collaboration and advanced robotics improves the safety and ergonomics, which automate hazardous jobs and fulfil the human-centric aspect of I5.0 (Bucci *et al.*, 2024) and address SDG 8 (decent work and economic growth). Blockchain and digital product passport strengthen the traceability in supply chain, allow supplier and leadership to verify ethical sourcing and comply with regulatory demands (Saleheen and Afrid, 2023). It addresses SDG 12 and SDG 16 (strong institutions). The use of AR- and VR-based solutions enhances standardisation and workforce training through immersive work instructions and remote assistance (Nagaraj and Shankar, 2025). It helps HR teams to shorten the time to competency. Through the dashboards, leadership can track the real-time performance, identify areas to lower logistics emissions and contribute towards SDG 9, SDG 13 and SDG 17. The use of life cycle assessment tools can guide leadership in eco design, zero waste roadmaps and circular production models (Raghav *et al.*, 2025), while emotional AI and ergonomics analytics can give HR and managers insights into employee engagement, stress levels and safety risks (Fiegler-Rudol *et al.*, 2025).

RQ2. How does OPEX in I5.0 promote collaboration and shared value creation among multiple stakeholders?

The OPEX within the I5.0 reshapes the roles, expectations and outcomes for both internal and external stakeholders because of involvement of human-centricity, sustainability and resiliency aspects into core operations (Fiegler-Rudol *et al.*, 2025). For workers, OPEX in I5.0 enhances safety, engagement and inclusion. The human–robot collaboration allows workers to focus more on creativity and decision-intensive activities (Souza *et al.*, 2025). Access to AR- and VR-based work instructions, real-time feedback through IoT devices, can help to enhance job satisfaction and reduce fatigue (Ponis *et al.*, 2020), which contributes to SDG8 (Decent work). Managers can use AI and digital twins to provide insights on process stability, risk scenarios and bottlenecks (Mihai *et al.*, 2022). This will help to enable responsiveness and alignment of performance with sustainability and resiliency, which contributes to SDG 9 (Industry, Innovation) and SDG 13 (Climate Action). Human resource (HR) teams benefit from data-driven talent management and improve employee well-being (Nocker and Sena, 2019). Emotional AI and ergonomics analytics will allow proactive monitoring of workforce engagement and stress, while competency frameworks and adaptive learning platforms support continuous skill development (Gill and Mathur, 2024). As I5.0 promotes collaborative, sustainable ecosystems, suppliers can gain from

synchronised planning and blockchain-enabled traceability, while customers can take benefit from reliable, high-quality and low-impact products (Alabi, 2025). Policymakers and governments obtain real-time operational data for regulatory oversight which promotes public–private partnerships and aligned with SDG 12 (Responsible Production), SDG 16 (Institutions) and SDG 17 (Partnerships).

To provide more understanding about *RQ1* and *RQ2*, we have proposed a framework for OPEX in I5.0 to achieve SDGs, which is presented in Figure 2.

RQ3. What strategic insights from literature can help organisations redesign OPEX practices to align with the human-centric, sustainable and resilient goals of I5.0?

To address *RQ3*, the authors have done multiple brainstorming sessions and discussions aimed at envisioning the future of OPEX in I5.0. These discussions were used to map the potential research gaps and propose open research questions (ORQs) that can provide the foundation for future investigations on OPEX in I5.0. The intent of formulating these ORQs is to encourage deeper inquiry into how next-generation OPEX frameworks, when shaped by I5.0 principles and technologies, can contribute to achieving the SDGs. As industries are increasingly expected to align operational performance with broader sustainability objectives, these ORQs are important to guide future studies in this evolving domain. The propositions developed in this study are grounded in the theoretical and empirical literature on I5.0, OPEX and sustainability. The rationale for their formulation lies in the growing need to understand how advanced technologies, human-centric design and sustainable practices can influence the operational outcomes. Prior studies have also highlighted that cobots, digital twins and artificial intelligence not only improve productivity but also support sustainable operations and workforce well-being (Hajjem *et al.*, 2025; Rahman *et al.*, 2024). Similarly, the integration of blockchain and circular economy principles helps to improve transparency and resource efficiency, aligning OPEX with SDGs (Atiku *et al.*, 2024; Verma *et al.*, 2022). Based on these insights, the propositions in this study are developed to conceptually link I5.0 and stakeholder collaboration with OPEX toward achieving sustainability and resilience.

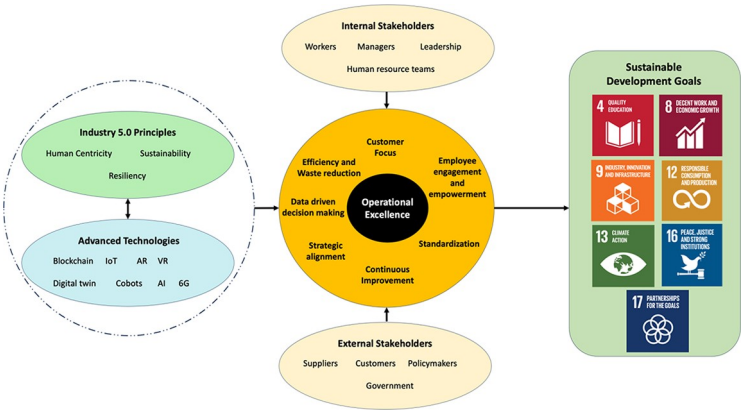

Figure 2. OPEX framework in Industry 5.0 to achieve SDG
Source: Authors' own work

From an internal stakeholder perspective, there is a growing need to understand how OPEX practices can evolve within the human-centric, sustainable and resilient vision of I5.0. Most existing OPEX models are efficiency-oriented and have a limited perspective on worker well-being, inclusion and creativity. Therefore, we propose:

ORQ1. How can human-centric design principles be integrated into OPEX practices to enhance worker well-being and creativity in I5.0 environments? (SDG 3, SDG 8).

While technological systems such as AI, Digital Twins and IoT have been widely used, their role in driving continuous improvement and a zero-defect culture through managerial practices remains underexplored. Therefore, we propose:

ORQ2. What role can advanced digital technologies such as AI, Digital Twins and IoT play in strengthening OPEX practices within I5.0? (SDG 9, SDG 12).

Traditional OPEX systems have less focus on the integration of environmental KPIs, which limits managers' ability to support low-carbon transitions. Therefore, we propose:

ORQ3. How can data-driven decision-making in OPEX be leveraged within I5.0 to promote low-carbon and resource-efficient operations? (SDG 13, SDG 12).

Workforce well-being is often overlooked in operational systems despite its strong link to performance. Therefore, we propose:

ORQ4. How can emotional-AI and ergonomics analytics be embedded into OPEX practices in I5.0 to enhance workforce engagement and retention? (SDG 3, SDG 8).

For human resource teams, preparing a future-ready workforce is critical, yet current training systems remain slow and inconsistent because of a lack of skills. Therefore, we propose:

ORQ5. How can AR- and VR-based training systems be used to accelerate skill development and reduce variability in human-centric OPEX systems? (SDG 4, SDG 8).

HR systems also lack frameworks to measure and align human-centric capabilities with organisational strategy. Therefore, we propose:

ORQ6. What competency frameworks can align digital, sustainability and human-centric capabilities with OPEX objectives in I5.0? (SDG 8, SDG 9).

Leadership plays a vital role in driving this transformation, yet leaders often struggle to incorporate sustainability objectives into daily operational routines. Therefore, we propose:

ORQ7. How can leadership practices align OPEX systems with long-term sustainability and resilience goals in I5.0? (SDG 9, SDG 13).

Moreover, many organisations still operate on I4.0 logics, which leads to a barrier in the form of resistance to cultural change. Therefore, we propose:

ORQ8. What change management strategies are effective for transitioning from efficiency-focused OPEX to human-centric and sustainable OPEX in I5.0? (SDG 9, SDG 12).

OPEX metrics are still more focused on cost, quality and delivery, overlooking social and environmental dimensions. Therefore, we propose:

ORQ9. What performance indicators can holistically capture the human-centric, sustainable and resilient outcomes of OPEX in I5.0? (SDG 8, SDG 13).

From an external stakeholder perspective, achieving OPEX requires stronger ecosystem-wide alignment, yet current OPEX models remain organisation-centric. Supply networks lack common governance and traceability mechanisms, limiting shared responsibility. Therefore, we propose:

ORQ10. What governance mechanisms can align supplier networks with OPEX principles in I5.0 to ensure ethical sourcing and traceability? (SDG 12, SDG 16, SDG 17).

Similarly, emerging Blockchain-based digital product passports have the potential to transform traceability and circularity, but less attention has been paid to them in the literature. Therefore, we propose:

ORQ11. How can blockchain-enabled digital product passports be incorporated into OPEX frameworks in I5.0 to enhance transparency and circularity? (SDG 12, SDG 9).

Suppliers are also struggling to align capacity and quality systems with buyer expectations in real time. Therefore, we propose:

ORQ12. How can collaborative planning tools support supplier integration into OPEX-driven I5.0 production systems? (SDG 9, SDG 17).

Customers are becoming more sustainability-conscious, yet most OPEX systems do not measure or communicate environmental value to them. Therefore, we propose:

ORQ13. How can OPEX systems in I5.0 communicate sustainability performance to customers to enhance trust and engagement? (SDG 12, SDG 13).

Customer feedback also remains underused in operational improvement cycles most of the time. Therefore, we propose:

ORQ14. How can real-time customer feedback be incorporated into OPEX routines to accelerate innovation in I5.0? (SDG 9, SDG 12).

For policymakers, there is a challenge to set up regulations and incentives that promote sustainable OPEX without restricting innovation. Therefore, we propose:

ORQ15. What policy instruments can encourage organisations to adopt OPEX practices aligned with the human-centric and sustainable principles of I5.0? (SDG 9, SDG 17).

Policymakers also lack access to reliable performance data for regulatory decision-making. Therefore, we propose:

ORQ16. How can standardised reporting frameworks support policymakers in monitoring OPEX performance across industries in the I5.0 era? (SDG 16, SDG 17).

Governments play a strategic role in orchestrating large-scale I5.0 transitions. Therefore, we propose:

ORQ17. How can national industrial strategies embed OPEX principles to accelerate progress towards the SDGs in the context of I5.0? (SDG 9, SDG 13, SDG 17).

5. Implications of this study

5.1 Theoretical implications

The theoretical implication of the present study provides an understanding of how OPEX is being reshaped within the I5.0 environment and aligned with SDGs. The present study contributes to theory by extending the concept of OPEX beyond the traditional boundaries of cost, quality and efficiency, positioning it within the emerging paradigm of I5.0. Previous studies have primarily discussed OPEX in the context of I4.0 and focused on digital integration and process efficiency (Chiarini and Kumar, 2021; Miandar *et al.*, 2020). However, limited work has examined how OPEX evolves when human-centricity, resilience and sustainability are integrated into the operational systems.

Therefore, the present study highlights the potential of both digital and physical technologies, such as AI, digital twin, cobots and IoT, to transform the traditional efficiency-driven operational models into the human-centric, sustainable and resilient systems which are core components of I5.0. The article also demonstrates how the advanced technologies support predictive, adaptive and collaborative operational environments and enable organisations to improve their performance and incorporate sustainability goals. This study reframes the discourse around OPEX by shifting the emphasis from linear efficiency metrics toward stakeholder-centric value creation, where employee well-being, innovation, ethical sourcing and circularity become integral to OPEX. It also advances theory by positioning human-centricity, sustainability and resilience as foundational principles for OPEX in Industry 5.0, thus extending classic operational theories that largely prioritised cost, quality and delivery outcomes. The article also proposes a framework for OPEX in I5.0, which can serve as the conceptual lens to systematically integrate I5.0 with organisational processes, stakeholder engagement and sustainability outcomes. This framework can guide future research on how technological and human factors co-evolve to enable OPEX that contributes to SDGs.

5.2 Managerial implications

The integration of advanced technologies within the OPEX practices in I5.0 has significant managerial implications for organisations striving to align their operational strategies with SDGs. Therefore, in the context of Ibero-American countries, this is important for managers as they are dealing with dual pressures, including productivity enhancement while responding to growing demands for social responsibility and environmental stewardship (Alcaraz *et al.*, 2019). According to PwC, organisations that develop I5.0 capabilities, including human-centric design and advanced digital platforms, can expect average revenue improvements of nearly 6.4% within one to two years. This highlights the urgency for managers to adopt OPEX within the I5.0 framework that combines technology, people and purpose [4].

Therefore, 5.0-driven OPEX strategies can be helpful in industries in this region to improve their performance as well as contribute towards SDGs. In I5.0, managers are expected to go beyond the efficiency targets and leverage technologies such as AI, digital twin and cobots to build human-centric, sustainable and resilient operations. For instance,

using AI-driven predictive analytics can allow managers to predict equipment failures, quality deviations, improve resource usage and reduce downtime, which supports SDG9 and SDG 12. Use of AR and VR-based training systems can help HR teams to rapidly upskill workers, embed safety practices which support SDG8. Integration of emotional AI and ergonomics analytics can help managers to monitor workforce well-being, stress levels and engagement in real time. This will also allow them to create an inclusive as well as psychologically safe environment which promotes creativity, collaboration and retention. Blockchain technology can be helpful to enable traceability and compliance while promoting trust and transparency across the supply chain. The regional industry reports, such as EY's, also highlight the practical roadmaps for transitioning from I4.0 to 5.0, emphasising worker upskilling, circular economy practices and human–machine synergy [5]. These insights support our recommendations for managers in the Ibero-American context to integrate OPEX strategies within I4.0 to achieve both operational performance and SDG outcomes.

6. Conclusions

This article presents a collective perspective on the application of emerging technologies to reshape OPEX within the I5.0 environment to support SDGs. This study highlights how technologies such as AI, digital twins, IoT, blockchain and AR are transforming conventional efficiency-driven systems into human-centric, sustainable and resilient operations. Unlike traditional approaches, which are more focused on cost reduction and throughput, I5.0 prioritise workforce well-being, stakeholder collaboration and environmental stewardship.

In this context, OPEX is evolving beyond process optimisation and is becoming a vehicle for long-term value creation across diverse stakeholder groups. AI-driven analytics, for instance, can be used to detect equipment failures in early stages, which enables preventive action and reduces material waste, while digital twins allow organisations to simulate operational changes before deployment and reduce risk. Similarly, AR-/VR-based training platforms can help to build workforce competence quickly and ensure standardisation without undermining human creativity. Emotional AI and ergonomics analytics can help to track workforce well-being, which enables organisations to align performance objectives with employee engagement. Blockchain-based product passports can help to strengthen transparency and traceability across supply chains. It will help to build trust with regulators, consumers and global partners.

However, the integration of these technologies into OPEX practices brings several challenges and limitations. One major concern is data privacy and cybersecurity. The risk of data breaches or misuse can undermine trust among employees, suppliers and customers. Strong data governance frameworks, ethical guidelines and secure data architectures will be essential to build trust and protect sensitive information. Another limitation is the digital divide between large, resource-rich firms and smaller enterprises. High upfront costs of digital infrastructure, licensing and continuous upgrades may exclude small and medium-sized enterprises.

Moreover, over-reliance on automation can reduce human agency in decision-making, potentially contradicting the human-centric ethos of I5.0. While automation enhances efficiency, excessive delegation of strategic functions to AI-driven systems can dilute managerial judgment and undermine workforce creativity. This raises ethical questions about how far decision-making should be automated in operational contexts, especially when algorithmic bias may influence decisions on workforce performance, supplier selection or risk scoring. In addition, most existing technologies and frameworks have been designed

within the logic of I.0 and are not yet fully adapted to the multi-stakeholder, collaborative model envisioned by I5.0.

Although the present study provides both theoretical and practical insights into how OPEX evolves within the I5.0 paradigm, it also opens several avenues for future research. First, future studies can explore empirical or longitudinal approaches to validate the conceptual linkages proposed in this study. Second sector-specific analyses, for example, manufacturing, logistics or health care, can be explored to reveal the variations in how OPEX in I5.0 supports the sustainability and human-centric outcomes. Third, comparative studies across the regions, including Ibero-American and non-Ibero-American contexts, would help to identify contextual factors influencing adoption. Researchers may explore the role of policy frameworks, digital maturity and leadership behaviour to achieve the OPEX. These directions will help guide the practitioners to integrate human-centric, resilient and sustainable practices into the real-world operations.

Notes

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