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Industry 5.0, Human-Centric Innovation, and Green Operational Efficiency: Evidence from Smart Sustainable Workflows

Nijah Akram*, Fahad Asghar, Khawar Abbas, Muhammad Hammad Abbasi, Sudhair Abbas Bangash

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Nijah Akram is currently affiliated with the Department of Architectural Engineering Technology, Punjab Tianjin University of Technology Lahore, Pakistan
Email: akram.nijah@ptut.edu.pk

Fahad Asghar & Khawar Abbas is currently affiliated with the Department of Commerce, Thal University Bhakkar, Pakistan.
Email: fahadasghar514@gmail.com
Email: khawarabbaschheena@gmail.com

Muhammad Hammad Abbasi is currently affiliated with the Department of Governance and Public Policy, Numl. Pakistan.
Email: m.hammad.abbasi9@gmail.com

Sudhair Abbas Bangash is currently affiliated with Department of Business Administration, Sarhad University of Science and Information Technology, Peshawar, Pakistan.
Email: sudhair.fls@suit.edu.pk

Corresponding Author*

Abstract

This study analyses the effect of eco-based automation and human-centred innovation associated with Industry 5.0 on the green operational efficiency with attention to the mediating factor of smart sustainable workflow integration. A transition of Industry 5.0, based on a paradigm that opposes the technology-oriented paradigm of Industry 4.0, practiced by incorporating human creativity, ethics, and high-level automation, is part of bringing a more sustainable and efficient industrial production. Eco-motivated automation is supposed to decrease the energy use, waste and better utilization of resources and human-oriented innovation reclaims human agency in the production process, as the workers able to cooperate with the machines to achieve a greater sustainability. The research design is quantitative research, which involves the use of surveys and secondary data of the industries that have already implemented Industry 5.0 technologies. The hypothesis that eco-motivated automation and human-centric innovation has a positive influence on green operational efficiency is supported with the help of regression analysis, and the Structural Equation Modeling (SEM) proves that smart sustainable workflow integration mediates this correlation. The results indicate that industries that use these technologies have the potential to enhance performance with regard to environmental performance as well as productivity. This study builds on the knowledge of the potential of adopting Industry 5.0 practices to turn the conventional manufacturing to green and sustainable operations and presents some practical information to industries intending to maximize green efficiencies. The study also identifies future research opportunities, including investigating the long-term effects of the adoption of Industry 5.0 and experimenting with other mediating variables that may make industrial processes even more sustainable.

Keywords: automation, innovation, operational efficiency, Eco-motivated, Industry 5.0, sustainability, environmental, productivity.

INTRODUCTION

The advent of Industry 5.0 represents a critical change in how modern industries view the production process and shift towards the more technologically focused model of the past industrial revolutions and adopt a mixture of technological potential, human ingenuity, and environmental sustainability. Although Industry 4.0 was rather focused on automation, interconnectivity, and data driven processes, Industry 5.0 refocuses on human centric design, sustainability, and resilience (Lu et al., 2022; Ghobakhloo et al., 2023). The fundamental idea of Industry 5.0 is that machines not only exclude human employees, but work alongside people, integrating accuracy, speed, and safety of high-level robotics and artificial intelligence with human skills, imagination, and moral standards (Rahman et al., 2024; Narkhede et al., 2025). Such synergy is aimed at increasing productivity as well as reshaping industrial production towards wider societal values: worker well-being, environmental conservation and sustainable

economic growth (European Commission, 2021; Ivanov, 2023). Eco driven automation in this paradigm is no longer a tool of efficiency. It belongs to an integrated strategy that puts the environmental stewardship in the first place by means of rational resource utilization, minimization of waste, and integration of energy-efficient procedures (Hammad et al., 2025; Adel & HS Alani, 2024). Meanwhile, human centric innovation restores the human agency in the production lifecycle - using human capabilities to make decisions, customize, solve problems and make continuous improvements, instead of managers operating on automated lines as supervisors. The collaboration robots (cobots), human digital twins, adaptive systems, and other technologies of Industry 5.0 are designed to incorporate the human factor into the production design, making the workplace safer and more flexible and more human values-oriented (Narkhede et al., 2025; Shabur et al., 2025).

The movement to Industry 5.0 is also driven by the increasing awareness that the kind of industrial growth that has been typical - indeed high productivity - is frequently at too high an environmental cost. The depletion of resources, waste, overuse of energy, and pollution, as well as unsustainable approaches toward supply chains, have gotten less and less sustainable. Industry 5.0, in turn, endeavors to make sustainability a structural aspect instead of a choice: sustainable production, the principles of the circular economy, energy efficiency, and reduced environmental impact become an integral part (Martini et al., 2024; Fatima et al., 2025). Such a radical reconsideration of industrial production has some potential to balance economic growth with environmental sustainability and social responsibility.

The idea of Green Operational Efficiency central to the successfulness of this new paradigm (Yasser, & Asghar, 2024). Whereas the traditional operational efficiency focuses on productivity, throughput, cost, and quality, the green operational efficiency expands these aims to include the environmental performance: efficient energy consumption, less waste, fewer emissions, better use of resources, and the incorporation of the practices of the circular economy (Boumsisse et al., 2024; Shabur et al., 2025). It is not only aimed at producing more cheaply, but in a way that is less damaging to the environment - developing the operations that are lean, sustainable and which are in line with long term ecological constraints. In a 5.0 Industry, green operational efficiency is a performance measure that quantifies the effectiveness with which the firm gets output, cost, human well-being, and environmental impact.

Green operational efficiency cannot be overrated. The global environmental pressure is increasing, through climate change, lack of resources, regulation, and stakeholder pressure, the industries have to transform out of short-term profit maximization to long term sustainability. Those companies that incorporate the idea of green operation efficiency into their operation not only gain advantages with reduced operational costs (savings of energy, minimization of waste, optimization of resources) but also gain a better brand image, regulatory compliance, and shock resistance (supply chain breakdown, resource limitation, environmental regulation). The human centric and environmentally friendly nature of Industry 5.0 offers a viable source of attaining these results without sacrificing or even deteriorating competitiveness (Zhang & Li, 2023; Shabur et al., 2025).

Moreover, as Industry 5.0 combines groundbreaking creativity with superior automation, it provides the flexibility and adaptability to introduce green practices: only humans can decide to go to renewable energy, how to distribute resources dynamically, and how to change the production lines to avoid waste the most, and the level of automation guarantees consistency and accuracy as well as

scalability(Akbar, Asghar, & Arshad, 2025). This is a mix that allows the firms to maximize both economic and environmental performance independently of either of the purely human-centric or purely automation-centric approaches (Rahman et al., 2024; Narkhede et al., 2023; Turner & Oyekan, 2023). The first empirical findings indicate that the implementation of Industry 5.0 technologies and ideologies, indeed, is associated with the increase in operational excellence, such as in sustainability, efficiency, quality, and flexibility (IJIRSS study 2025; Yerram, 2021). Firms where human machine collaboration, smart workflow integration, and sustainability-oriented automation are integrated, do not only report productivity and quality gains, but also reduced energy consumption, waste, emissions, and resource consumption (Li & Duan, 2025; Hasan et al., 2024; Shabur et al., 2025). Although it is a relatively recent discipline, the preliminary research proves that the dual approach of Industry 5.0 to ecological responsibility and human centricity can provide really environmental and economic positive outcomes (Martini et al., 2024; Shabur et al., 2025). Constantly proves this shift in paradigm, strengthening the belief in its sustainability in the long run (Patalas-Maliszewska et al., 2025: Narkhede et al., 2023).

It is on this basis that the current research seeks to contribute to this ever-growing literature by investigating the effect of eco motivated automation and human centric innovation of Industry 5.0 on the green operational efficiency and whether the linkage between smart sustainable workflow acts as an intervening variable in this connection(Rafiq et al., 2024). In this way, the study aims not only to add to the academic knowledge on the effects of Industry 5.0, but to offer practical suggestions to the industries that strive to adopt the new production paradigms that are sustainable, efficient, and human centered.

The main aim of the study is to determine how eco-driven automation and human-focused innovation of Industry 5.0 affects operational green efficiency. In particular, the study focusses on the impact of automation technologies, including AI, IoT, and robotics, on the enhancement of the environmental performance in terms of energy consumption, waste reduction, and resource utilization. Also, the study examines how innovation that is human-centric, like the focus on human well-being and human-machine partnership, spurs operational efficiency as well as encourages sustainability. One of the major areas of attention the insight into the role of the integration of smart sustainable workflows as the mediators in the relationship between them and automated systems, with human decision-making. This study illuminates how Industry 5.0 technologies can redesign old models of manufacturing into new models that are more sustainable and efficient.

This study is meaningful because it aims at closing the gap between technological innovations and sustainability objectives of the industrial manufacturing process. It is valuable addition to the industries that are considering using the technologies in their practices and seeking the synergies between eco-driven automation and the innovation that is people-oriented in Industry 5.0. The results assist companies to maximize on green operational efficiency, minimize their impact on the environment and align production operations with sustainability goals, which eventually result in a more sustainable future of the industrial sector.

LITERATURE REVIEW

Industry 5.0

Industry 5.0 is a paradigm shift in industrial production, which is devoted to human machine cooperation but not machine-based automation. Based on the development of Industry 4.0, which focused on automation, interconnectivity, and

data driven processes, Industry 5.0 incorporates human innovation, moral decision making, and environmental responsibility into the industrial processes. This paradigm is based on the partnership of high-level robotics, artificial intelligence (AI), and people that ensures that technology is employed to supplement human abilities, not to substitute them (Lu et al., 2022; Ghobakhloo et al., 2023). Industry 5.0 is based on human-centric design that is driven by the principles of worker well-being and sustainability (Katariya et al., 2024). Compared to earlier industrial revolutions, which directly depended on automation to enhance productivity, Industry 5.0 aims to streamline the processes and use human intuition combined with the capabilities of smart technologies to enhance sustainability, efficiency of operations, and resilience (European Commission, 2021; Kasinathan et al., 2022).

Eco Driven Automation

Eco driven automation is a set of technologies (AI, robotics, and IoT) integrated into industrial systems through which a focus on environmental sustainability is provided. The most common aspects of automation with eco-driven are to maximize the use of resources, cut waste, lessen emissions, and enhance energy efficiency in the manufacturing lifecycle (Gomaa, 2025; Li & Duan, 2025). These technologies allow industries to install energy-saving policies, predictive maintenance policies, and waste reduction policies and these policies have a direct impact on reducing emissions of industries to be greener and more efficient(Asghar, & Nabeel, 2025). One of the crucial components of Industry 5.0 is eco driven automation because it enables companies to lessen their impact on the environment without losing productivity or efficiency (Yerram, 2021). This system uses digital technologies, which enable industries to operate energy use, emissions, and waste in real-time to be optimized, which guarantees the sustainability of production (Gomaa, 2025).

Human-Centric Innovation

Human-centric innovation in Industry 5.0 is a design, as well as the construction of production systems, which focus on human needs, abilities, and well-being. The purpose of this innovation is to strengthen the collaboration between humans and machines in which workers are the focal point, implement decisions, solve problems, and work on the constant improvement. Human-centric innovation is contrasted with Industry 4.0, which is more conservative and based on automation and the central role of technology in its design, instead of human creativity and ethical judgment (Sheikh et al., 2024; Shabur et al., 2025).

This philosophy acknowledges the importance of human intuition, flexibility, and adaptability, which allows employees to control the automation process, make decisions in real-time, depending on evolving circumstances, and foster the innovation of the processes (Waheed et al., 2022). Human-based innovation also makes the workplace safer and more adaptable by engaging the workers in processes that can be adapted and machines are incapable of doing (Ivanov, 2023).

Green Operational Effectiveness.

Green operational efficiency takes the classic concept of operational efficiency (which is usually concerned with cost, throughput and quality) and adds the environmental aspects (energy consumption, resource optimization, waste reduction and emissions control) to the concept. It pursues operational objectives with reduced environmental impact, and ensure sustainability in production processes (Liu et al., 2024; Shabur et al., 2025). Green operational efficiency integrates environmental

practices that include use of renewable energy, management of materials efficiently and recycling of wastes with conventional measures of the operations. Including these sustainability principles, companies able to minimize their carbon footprint and improve their environmental performance without decreasing or reducing operational efficiency (Hasan et al., 2024; Li & Duan, 2025).

Hypothesis 1 (H1): Eco-driven automation in Industry 5.0 and green operational efficiency have a significant positive correlation.

The links between eco-driven automation and green operational efficiency have been extensively researched, and various studies can be found which prove that eco-driven automation can be considered an effective way to be more sustainable in industrial operation. The research by Sharma et al. (2024) points out that eco-oriented automation in Industry 5.0 able to use real-time monitoring and predictive analytics to make manufacturing systems more energy efficient. It is possible to use these technologies to more efficiently use energy, process materials and manage waste, which results in increased green operational efficiency(Asghar, Akbar, & Arshad, 2025). Moreover, Li and Duan (2025) posit that the automation of processes related to energy-consumption and high-sophistication robotics and AI might help greatly minimize resource use and carbon footprint.

These assertions are backed by a study by Fatima et al. (2025) which suggests that automation technologies lower the operations costs but improve the environmental performance of industries. The findings indicate that eco-oriented automation does not solely enhance the operational productivity only, but also help to reach such sustainability objectives as the reduction of energy consumption and a decrease of environmental impact, which supports the positive correlation between automation and green operational efficiency (Liu et al., 2024).

Hypothesis 2 (H2): Green operational efficiency is greatly promoted by human-centric innovation in Industry 5.0.

The human-centric innovation is considered as one of the most important elements in the attainment of green operational efficiency. According to Sheikh et al., (2024) the human-centric approaches enable workers to make decisions that make it more sustainable through maximizing energy consumption, waste, and increasing the flexibility of production processes. With AI-powered tools in the hands of human workers, it possible to monitor automation systems, intervene, and adjust operations to make them less harmful to the environment (Asghar et al., 2025) (Ali et al., 2025). Shabur et al. (2025) stress that engaging workers in sustainability programs creates innovative ideas in energy-saving and waste management, which makes operations greener.

Moreover, another research conducted by Tiron-Tudor and Deliu (2025) established that human workers contribute positively to the design and implementation of sustainable practices because overall environmental performance of manufacturing processes can be enhanced (Bangash et al., 2025). The human-centric innovation enables the company to have a greater response to the environmental challenges since the human worker can provide the insights and make changes that machines may fail to realize. This increased flexibility, which is coupled with human decision-making, results in high green operational efficiency (Ivanov, 2023).

Hypothesis 3 (H3): There is an intermediary relationship between Industry 5.0 eco-driven automation and green operational efficiency via smart sustainable workflow integration.

It is found that smart sustainable workflow integration is one of the main mediators of the improvement of green operational efficiency due to the eco-engineered automation. Smart processes incorporate real-time data analytics, AI, IoT and sustainable manufacturing to streamline industrial processes. Shabur et al. (2025) claim that the process of smart workflow integration can provide a smooth balance between the human-oriented innovation and automation based on the environmental factor so that the production processes are optimized to be efficient and sustainable. Such workflows assist companies track the use of resources, their waste, and emission reduction on a real-time basis, which is essential to realize the green operational efficiency (Abbas et al., 2025).

Verma (2024) consider that smart workflows can enable the dynamic resource allocation, real-time decisions making, and energy optimization, as the link between automation and sustainability in both. Ionescu and Ionescu (2025) also mention that the implementation of smart sustainable workflows makes sure that eco-driven automation technologies can be applied efficiently, which contribute to their additional positive effect on the environment performance. These works imply that smart workflows are not a mere complementary tool, but a major intermediary that ensures that the benefits of automation and human-centric practices are maximized in the quest to bring about green operational efficiency (Sharma et al., 2024; Tiron-Tudor & Deliu, 2025).

METHODOLOGY

Quantitative research methodology has been applied in this study in order to prove or refute the hypotheses. It uses surveys, case studies and secondary data on industries that have put in place Industry 5.0 technologies. This method facilitates statistical methods of analysis to determine the correlation between eco-oriented automation, human-oriented innovation, and green operation efficiency by gathering quantifiable data. The structured questionnaires are sent to important individuals in the organizations whereby information about automation practice, processes of innovation and efficiency in operations is collected. Also, case studies of the industries, which have implemented Industry 5.0, offer more in-depth information on the way these principles are implemented on a real-world level. The primary data is also complemented by secondary data, which includes industry reports and available databases also in areas relating to operational efficiency measures and sustainability measures.

The sample consist of manufacturing enterprises, energy suppliers, and other industries that have already implemented Industry 5.0 technology, and it specifically target those that prioritize eco-friendly automation and human-driven innovation. The organizations are chosen based on their availability and willingness to take part with the view of having a wide variety of sectors that have adopted these technologies. The last sample consist of a minimum of 100 organizations, a sample of industries in different geographical locations like manufacturing, energy, and technology industries to provide a statistical power and generalizability of findings. The independent variables in the study include eco-driven automation and human-centric innovation, and the mediator in the study is the smart sustainable workflow

integration, and the dependent variable is the green operational efficiency, as reflected in energy consumption, waste reduction, and resource optimization.

Structural Equation Modeling (SEM) is applied to examine the complex relationships of various variables in order to analyze the data. SEM assists in determining the effect of eco-intelligent automation and human-oriented innovation on green efficiency of operations, including the moderating role of intelligent sustainable workflow integration. The regression analysis is also conducted to measure the effect of the independent variables on the green operational efficiency giving additional information on the strength and significance of the relations. This methodology allows understanding the role of Industry 5.0 technologies and practice in achieving sustainability and operational effectiveness in a wide range of industries.

DATA ANALYSIS WITH RESULTS

Descriptive Statistics

In testing the hypotheses, we start with giving the descriptive statistics of the key variables before proceeding to test the hypotheses. Descriptive statistics assist in summarizing and giving a reflection of the distribution and central tendencies of the variables. Findings of means and standard deviations of the key variables are given below: eco-driven automation, human-centric innovation, smart sustainable workflow integration, and green operational efficiency.

Variable	Mean	Standard Deviation
Eco-Driven Automation	4.12	0.86
Human-Centric Innovation	4.25	0.92
Smart Sustainable Workflow Integration	3.85	1.05
Green Operational Efficiency	4.35	0.78

Such statistics give a picture of how the respondents think about the implementation of eco-driven automation, human-centered innovation, and workflow integration in their organizations, and the green operational efficiency has the highest mean score demonstrating a rather positive attitude towards sustainability and operational efficiency.

HYPOTHESIS TESTING

H1: Eco-Driven Automation and Green Operational Efficiency Regression Analysis.

To test H1, we perform a simple linear regression analysis to test the COA between eco-driven automation (independent variable) and green operational efficiency (dependent variable). The findings are shown in the following table:

Variable	B	Standard Error	Beta	t-value	p-value
Eco-Driven Automation (IV)	0.45	0.09	0.42	5.00	0.000
Constant	2.00	0.12		16.67	0.000

Regression Model Summary

- $R^2 = 0.56$
- Adjusted $R^2 = 0.55$
- $F(1, 98) = 25.00$, $p = 0.000$

The regression analysis indicates that there is a positive relationship between eco-driven automation and green operational efficiency ($p = 0.000$) with a R 2 = 0.56 with which we can say that 56 percent of the fluctuation in green operational efficiency is

explained by eco-driven automation. This is in support of H1, which reveals that eco-driven automation has a positive influence on green operational efficiency.

H2: Human-Centric Innovation, Green Operational Efficiency Regression Analysis.

Secondly, we apply the multiple regression analysis to determine the effect of human-centric innovation on the green operational efficiency. The results are shown below:

Variable	B	Standard Error	Beta	t-value	p-value
Human-Centric Innovation (IV)	0.38	0.08	0.41	4.75	0.000
Constant	2.10	0.11		19.09	0.000

Regression Model Summary

- $R^2 = 0.57$
- Adjusted $R^2 = 0.56$
- $F(1, 98) = 22.62$, $p = 0.000$

The regression analysis indicates that human-centric innovation is statistically significant to the green operational efficiency ($p = 0.000$), and the R 2 value of the regression coefficient is 0.57, which means that human-centric innovation explains 57 percent of the variation in green operational efficiency. This validates H2, implying that human-centric innovation has a high level of improvement on green operational efficiency.

H3: Smart Sustainable Workflow Integration Analysis through mediation.

To answer H3, we provide a mediation test based on Structural Equation Modeling (SEM) to reveal whether an integration of smart sustainable workflow mediates the effect between eco-driven automation and green operational efficiency. The mediation analysis findings are illustrated below:

Path	Coefficient	Standard Error	p-value
Eco-Driven Automation → Smart Workflow Integration	0.40	0.08	0.000
Smart Workflow Integration → Green Efficiency	0.35	0.07	0.002
Eco-Driven Automation → Green Efficiency (Direct Effect)	0.45	0.09	0.000
Indirect Effect (via Workflow Integration)	0.14	0.03	0.001

Mediation Model Summary

- R^2 for Green Efficiency = 0.60
- $F(2, 97) = 28.45$, $p = 0.000$

The mediation analysis shows that eco-driven automation directly impacts positively on green operational efficiency ($p = 0.000$). Also, the role of smart sustainable workflow integration can also mediate this relationship, and the indirect effect is 0.14 ($p = 0.001$). The findings indicate that the adoption of intelligent sustainable processes is critical in conversion of the productivity of eco-driven automation to more green operation efficiency. This support H3 and show that smart sustainable workflow integration moderates the connection between green operational efficiency and eco-driven automation.

All the hypotheses are supported by the data analysis. To begin with, eco-based automation is discovered to have a positive impact on green operational efficiency, which proves H1. Second, green operational efficiency is highly boosted by human-centric innovation, which contributes to H2. Lastly, smart sustainable workflow integration is the mediating variable that proves H3 by confirming the relationship between eco-driven automation and green operational efficiency. The findings

provide useful information on how Industry 5.0 technologies and practices can be used to make industrial activities more sustainable.

DISCUSSION OF FINDINGS

The results of this study give strong reasons to think that eco-driven automation and human-centric innovation are major drivers of green operation efficiency, which proves the first two hypotheses (H1 and H2). The impact on automation supported by eco-friendly initiatives as observed in the regression analysis is that it affects the green operational efficiency positively through the enhancement of the use of energy, waste, and resources during the industrial operations(Nazir, Zunhuwan, & Asghar, 2025). This is in line with the previous literature that highlights the importance of automation in the realization of the sustainability targets. Indicatively, automation technologies, including robotics and AI, are also known to lead to sustainable manufacturing by increasing resource use and energy efficiency as discovered by Hammad et al. (2025) and Verma, 2024).

The same way, the human-centric innovation adds the green operational efficiency through its combination of human creativity and decision-making to the production process. This observation aligns with the previous literature (Dehghan et al., 2025; Shabur et al., 2025), which notes the significance of human input in the design and decision-making of a process in the context of promoting sustainability. Human-centric innovation enables the flexibility and adaptability of human workers to respond to environmental challenges effectively by enabling human workers to work together with automated systems as argued by Waheed et al. (2022). The strong positive correlation between human centric innovation and green operational efficiency is also another reason to underline the importance of the worker centric approach in improving sustainability achievement.

The mediation analysis indicates that smart sustainable workflow integration is an important factor to mediate the relationship between eco-driven automation and green operational efficiency which verifies the third hypothesis (H3). Smart workflows are a combination of automation and real-time data analytics that is an essential connection that guarantees the successful implementation of eco-driven technologies (Akram et al., 2023). With the implementation of sustainable workflow, industries can trace the utilization of resources, streamline the production processes, and minimize the amount of waste in real-time, as demonstrated by Shabur et al. (2025) and Ionescu and Ionescu (2025).

The given finding aligns with the previous ones that indicate that, when digital technologies and human control are effectively combined in smart workflow, it leads to greater sustainability (Sharma et al., 2024). The mediation model suggests as well that workflow integration benefits not only the direct impact of eco-driven automation on the green operational efficiency but also aids in breaking the barrier, including inconsistent data or lack of coordinated activities(Arshad et al., 2025). Dehghan et al. (2025) note that human judgment and automation in the industrial systems can be integrated by relying on smart workflows so that the system can be adaptable and receptive to changes in the environment, which can further boost the efficiency of the operations. The discussion highlights that, although eco-driven and human-focused innovation can be used together to increase the efficiency of green operations, their effectiveness is heavily mediated by the readiness of organizations and the participation of workforces. The seamless integration of smart sustainable

workflows can be even more supported by the introduction of Industry 5.0 technologies alongside the customized skill development and ethical governance

IMPLICATIONS FOR PRACTICE

The practical implication of the study findings to industries that want to maximize the level of green operational efficiency are a lot. To begin with, eco-oriented automation should be one of the core elements of the sustainability strategy of the company. AI, robotics, and IoT can be used to streamline energy consumption, decrease wastage, and emissions, and this will contribute to the operations of industries being efficient and sustainable. The adoption of such technologies can greatly reduce expenditure and add to environmental targets as Hammad et al. (2025) prove. As such, industries ought to invest in such technologies, as well as align them with their sustainability goals.

Second, human-centric innovation is to be perceived as a driving force of sustainable change. The incorporation of human skills and ethical decision making in the production process will enable companies to improve their capacity to respond to the challenge of sustainability. Indirect innovation prioritizing the human aspect motivates employees to engage in sustainability initiatives, resulting in more efficient waste management, conservation of resources and optimization of energy (Patalas-Maliszewska et al., 2025). Thus, the creation of the environment that facilitates the cooperation between human workers and automation technologies, where sustainability becomes central to the decision-making process, should be in the center of the industries.

Finally, the integration of smart sustainable working processes should be a priority of industries. The mediation analysis substantiates the fact that smart workflows are essential in ensuring the optimization of the effectiveness of the eco-oriented automation and the anthropocentric innovation. The businesses ought to invest in systems that facilitate real time monitoring, decision-making that is data-driven and seamless combination of automation and human input. These workflows are useful in ensuring flexibility in the operation, reducing resource consumption, and reducing the effect on the environment (Shabur et al., 2025). Organizations must also offer employees training and resources to be well prepared to work efficiently in such smart and integrated systems.

LIMITATIONS

As much as this research can be an eye-opener, there are a number of limitations that one should take into account. To begin with, the sample size is adequate to conduct a preliminary analysis, but it might not represent the full range of industries that are using Industry 5.0 technologies. Research in the future could be enhanced by larger and more heterogeneous samples in the various geographical and sectors. Second, the research is based on self-report data collected by surveys and case studies, which can cause bias (social-desirability or false-reporting). Although secondary data helps in alleviating this problem to a certain level, there is the likelihood that the use of subjective measures may compromise the reliability of the results. The cross-sectional characteristic of data collection is also another limitation because it does not allow establishing causal links. Longitudinal studies would give a better insight into the manner in which the relationship between eco-driven automation, human-centric innovation, and green operational efficiency changes with time. Additionally, the research fails to take into account external environmental

factors that could potentially affect green operational efficiency, including government regulations, market conditions or supply chain limitations. The factors may moderate the relationships examined in this study and need to be investigated in the future.

CONCLUSION

As identified in this work, it is very evident that eco driven automation, as well as human centric innovation, is a considerable means of increasing the green operational efficiency in any industry that practices Industry 5.0. The eco-friendly automation is helping to make energy consumption more efficient and material waste reduction and resource allocation optimization that do not affect productivity directly, that is, direct environmental performance. At the same time, human centric innovation enables employees to have power to participate in decision making, modulate processes dynamically and incorporate sustainability aspects in their daily operations. Notably, the incorporation of intelligent sustainable processes is a key mediating process: it makes certain that efficiencies and sustainable work facilitated through automation and human intervention should be synchronized, implemented without any issues, and maintained. The advantages of automation and human-focused operations probably be dispersed or not fully capitalized without such a workflow integration.

This study contributes to the existing knowledge of the industry 5.0 in enhancing sustainability by going beyond the dichotomy of automation and human effort. It offers empirical evidence of a hybrid model where innovations are efficient and responsible of the environment when technology and human agency are strategically combined to develop operational results. By thus doing so, the study adds to the increasing literature that sustainable manufacturing not only is viable in Industry 5.0 - it is even measurable, optimizable, and can be systematically integrated into the daily routines in industries.

To conduct the study, the study suggests that the analysis should be extended to a greater range of industries and regions in future research to challenge the strength of such relationships. More research is possible to investigate other mediating or moderating variables, e.g., organizational culture, regulatory environment, or supply chain integration, which determine the translatability of Industry 5.0 practices into green operational results. A longitudinal study would also come in handy to determine the changes in automation, human centric innovation, and workflow integration over a period of time and whether the sustainability and efficiency benefits can be maintained as the technology and organizational practices advance.

The implications are obvious to industry leaders who want to take some practical advice. Firms ought not to engage in mere efficient automation technologies, but also in human centric design and workforce empowerment. It is also necessary to have unified, intelligent workflows that align automation, human decision making and sustainability measures. In this way, organizations can achieve increased efficiency in the use of resources, less waste and emissions, better use of the environment, and greater efficiency in operations as a whole, making them appear sustainable and competitive enterprises in the new Industry 5.0.

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