



How Industry 4.0 and Knowledge Management Shape Sustainable Performance Unequally?

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Abstract

Background: Pharmaceutical manufacturers face growing pressure to achieve sustainable performance while meeting strict regulations and adapting to digital transformation. However, the impact of Industry 4.0 technologies and knowledge management on sustainable performance remains inconsistent, especially in highly regulated environments.

Objective: This study investigates the differing effects of Industry 4.0 and knowledge management on sustainable performance and explores the moderating role of transformational leadership in pharmaceutical manufacturing.

Methods: Survey data were collected from 425 managers working at Good Manufacturing Practice (GMP)-certified pharmaceutical firms in the Jabodetabek region of Indonesia and analyzed using partial least squares structural equation modeling (PLS-SEM).

Results: The results demonstrate that Industry 4.0 has a positive and significant direct effect on sustainable performance, confirming its role as an operational enabler in regulated environments. In contrast, knowledge management has no significant direct effect on sustainable performance, indicating that its contribution remains limited when it is primarily associated with compliance and documentation practices. Transformational leadership negatively moderates the relationship between Industry 4.0 and sustainable performance, suggesting a misalignment between this leadership style and the need for process stability during the early stages of digital implementation. Conversely, transformational leadership positively moderates the relationship between knowledge management and sustainable performance, indicating that leadership conditions influence the extent to which knowledge management contributes to performance outcomes.

Conclusion: These findings suggest that organizational capability effectiveness depends on alignment with leadership style. Managers should stabilize digital processes and promote knowledge management through learning-oriented leadership to improve sustainable performance.

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INTRODUCTION

Organizations are increasingly expected to achieve outcomes that extend beyond financial performance, reflecting the growing importance of sustainable performance in contemporary business practice (Bade et al., 2024; Jiang et al., 2024). This shift redefines organizational success by integrating environmental and social responsibilities into core managerial decision making rather than treating them as peripheral concerns (Bade et al., 2024). At the same time, firms must maintain operational efficiency while complying with evolving regulatory requirements, particularly in highly regulated industries (Bade et al., 2024; Mastrantonas et al., 2024). These

competing demands make the integration of sustainability into day to day operations increasingly complex, requiring firms to align strategic intent with operational constraints (Mastrantonas et al., 2024).

To address these pressures, organizations have increasingly relied on digital transformation and knowledge-based practices. Industry 4.0 is associated with enhanced data integration, improved process visibility, and stronger coordination, which are expected to support sustainable performance (Cheng et al., 2024; Jayashree et al., 2021). However, empirical evidence shows that the performance outcomes of digital transformation remain uneven, particularly in developing economies and highly regulated environments where adoption is often partial and constrained (Arief et al., 2022; Mastrantonas et al., 2024). Similarly, knowledge management is widely regarded as a strategic resource that supports learning and sustainability-oriented decision making, yet its direct contribution to sustainable performance remains inconsistent (Khan & Rauf, 2024; Martínez-Falcó et al., 2023).

These inconsistencies indicate that the relationship between digital and knowledge-based capabilities and sustainable performance is not inherently linear, but varies depending on organisational conditions. These inconsistencies suggest that digital and knowledge-based capabilities do not automatically translate into performance outcomes. While global studies predominantly report positive direct effects of Industry 4.0 on organizational performance Tao (2024) and Shahzad (2024), evidence from Indonesia and similarly constrained developing economies reveals a more nuanced picture: digital maturity remains partial, regulatory compliance dominates implementation priorities, and leadership alignment becomes a critical boundary condition absent in broader cross-national studies (Arief et al., 2022; Prakosa et al., 2024). This Indonesian pharmaceutical context, therefore, constitutes a theoretically important and empirically underexplored setting that challenges the generalizability of global findings.

These limitations become more evident in pharmaceutical manufacturing, where strict regulatory requirements, extensive validation processes, and limited operational flexibility constrain the extent to which organizational initiatives can directly improve sustainable performance (Badejo & Ierapetritou, 2024; Poku et al., 2025). Evidence from Indonesia indicates that digital adoption in manufacturing sectors is still limited in scope and maturity, constraining the extent to which digital technologies can generate broader operational and sustainability outcomes (Prakosa et al., 2024). In such environments, digital technologies are often implemented to strengthen operational control rather than to enable broader transformation, while knowledge management practices tend to emphasize documentation and compliance rather than value creation. As a result, the expected performance benefits of these capabilities may not fully materialize, highlighting the need to examine the conditions under which they become effective.

One critical condition is leadership. Transformational leadership is commonly associated with change facilitation and capability development; however, in compliance-driven environments, such leadership practices may not always align with the need for process stability, potentially influencing the effectiveness of digital and knowledge-based initiatives (Harsono et al., 2024). While prior studies have largely treated leadership as a uniformly enabling factor linking capabilities to performance Baah (2021); Hammami (2024); Umar (2025), emerging evidence suggests that its effects are contingent and may vary across contexts (Harsono et al., 2024). This reveals a critical gap, where the mechanisms and boundary conditions through which digital and knowledge-based capabilities are translated into sustainable performance remain insufficiently understood, particularly in highly regulated and early-stage digital environments. This indicates that the relationships among Industry 4.0, knowledge management, and sustainable performance are not necessarily linear or universally positive, particularly in highly regulated organizational settings.

From a theoretical perspective, these conditions can be explained through the Resource-Based View, which posits that organizational performance depends on the effective deployment of valuable and strategically managed resources. This perspective is extended by the Knowledge-Based View, which emphasizes knowledge as a critical resource for capability development and decision making (Grant, 1996). However, resources alone are insufficient to generate performance outcomes. The Dynamic Capability View further suggests that firms must be able to integrate, reconfigure, and align resources with environmental demands in order to sustain performance. In regulated environments, where flexibility is constrained and digital adoption

often remains at an early stage, the ability to translate digital and knowledge-based resources into sustainable performance becomes conditional rather than automatic.

Accordingly, Industry 4.0 and knowledge management can be understood as distinct organizational capabilities whose effectiveness depends on how they are aligned with operational conditions. Industry 4.0 enhances sustainable performance by improving process efficiency, coordination, and data-driven decision making, thereby supporting economic, environmental, and operational outcomes (Cheng et al., 2024; Tao & Chao, 2024). In contrast, knowledge management contributes by enabling the acquisition, integration, and application of knowledge, which supports decision quality and sustainability-oriented practices (Martínez-Falcó et al., 2023; Nasir et al., 2024). However, when knowledge processes are embedded within compliance-driven routines, their contribution may remain limited. These arguments suggest that both capabilities are expected to influence sustainable performance, although their effects may not be uniformly realized across contexts. Therefore, the following hypotheses are proposed:

H1. Industry 4.0 has a positive effect on sustainable performance.

H2. Knowledge management has a positive effect on sustainable performance.

The effectiveness of these capabilities is further shaped by leadership. Drawing on Path-Goal Theory, leadership effectiveness depends on alignment between leadership style, task requirements, and organizational context (House, 1971, 1996). Transformational leadership is commonly associated with change facilitation and capability development, which can strengthen the role of knowledge management by enabling knowledge application in organizational processes (Alhawamdeh et al., 2024; Ting et al., 2021). However, in line with the operational constraints described earlier, during early stages of Industry 4.0 implementation that require process stability and procedural discipline, transformational leadership may not align with these requirements, potentially weakening the effectiveness of digital initiatives (Harsono et al., 2024). This indicates that leadership does not operate as a uniformly enabling factor but as a contingent mechanism shaping how capabilities translate into performance outcomes.

Based on these arguments, this study examines how Industry 4.0 and knowledge management contribute to sustainable performance by considering the moderating role of transformational leadership in a highly regulated pharmaceutical manufacturing context. Rather than assuming uniformly positive relationships, the study investigates how the effectiveness of these capabilities depends on the alignment between capability type and leadership style. Therefore, the following hypotheses are proposed. This study aims to investigate the direct effects of Industry 4.0 and knowledge management on sustainable performance and to evaluate whether transformational leadership moderates the relationships between Industry 4.0 and sustainable performance and between knowledge management and sustainable performance.

H3. Transformational leadership moderates the effect of Industry 4.0 on sustainable performance.

H4. Transformational leadership moderates the effect of knowledge management on sustainable performance.

METHOD

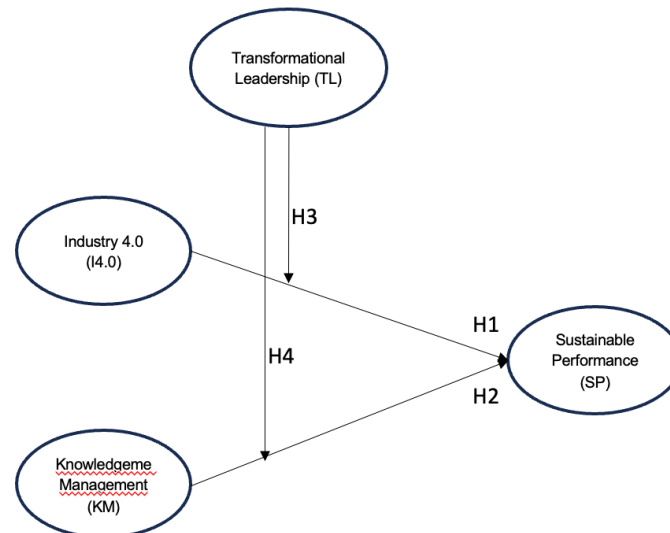


Figure 1. Research Framework

This study uses a quantitative survey design to examine the relationships among Industry 4.0, knowledge management, transformational leadership, and sustainable performance. The unit of analysis is the individual manager, and a cross-sectional approach was applied.

The population consists of pharmaceutical firms with Good Manufacturing Practice (GMP) (CPOB) certified injectable facilities. A purposive sampling technique was used to select respondents with relevant knowledge of digital transformation and organizational practices, restricted to managerial-level employees. Data were collected through an online questionnaire, resulting in 425 valid responses after screening.

All constructs were operationalized utilizing reflective measurement models that were adapted from established and validated scales. The capability of Industry 4.0 (I4.0) was assessed through eight items that reflect the degree of digital technology adoption and integration. Knowledge management (KM) was evaluated across four dimensions: knowledge acquisition, conversion, application, and protection. Transformational leadership (TL) was measured using seven items that represent inspirational motivation, intellectual stimulation, idealized influence, and individualized consideration. Sustainable performance (SP) was operationalized through indicators of economic, environmental, and social performance. Each measurement item was evaluated using a five-point Likert scale, ranging from strongly disagree to strongly agree.

Data analysis was performed using Partial Least Squares Structural Equation Modelling (PLS-SEM) via SmartPLS, which is suitable for models that incorporate multiple latent constructs and moderation effects. PLS-SEM was chosen over covariance-based SEM (CB-SEM) for three primary reasons: the complex nature of the research model, which includes both formative and reflective constructs; the study's focus on prediction and variance explanation rather than the validation of theoretical frameworks; and PLS-SEM's ability to effectively handle sample size and non-normal data distribution (Hair et al., 2019). The analysis was conducted in a two-phase approach. Initially, the measurement model was evaluated by examining indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. Subsequently, the structural model was analyzed by investigating path coefficients, predictive relevance, and the moderating effects of transformational leadership (TL) on the relationships between Industry 4.0 (I4.0) and strategic performance (SP), as well as between knowledge management (KM) and SP.

RESULTS AND DISCUSSION

Results

Respondent characteristics are presented in Table 1. The sample is balanced and professionally relevant, with representation from both genders and respondents largely in mid-career stages. Most hold undergraduate and postgraduate qualifications, indicating sufficient analytical capability. The dominance of managerial roles ensures insights from individuals involved in operational and strategic processes, supported by moderate to high work experience.

Overall, these characteristics support the credibility and relevance of the data for analyzing the study variables.

Table 1. Respondent Profile

Characteristic	Categories	Frequency	Percentage
Gender	Male	228	53.6%
	Female	197	46.6%
Age	< 25	1	0.2%
	25-30	84	19.8%
	31-40	192	45.2%
	41-50	131	30.8%
	>50	17	4.0%
Education	Bachelor	247	58.1%
	Masters	173	40.7%
	Doctorate	5	1.2%
Job Level	Manager	306	72.0%
	General Manager	99	23.3%
	Director	20	4.7%
	CEO	0	0%
Experience	1-2 years	31	20.0%
	3-5 years	120	28.2%
	6-8 years	141	33.2%
	9-10 years	79	18.6%
	>10 years	54	12.7%

All constructs satisfy the criteria for reliability and validity. The outer loadings are greater than 0.60. Both Cronbach's Alpha and Composite Reliability are above 0.70. The Average Variance Extracted values are higher than 0.50. VIF values remain below 3.3, suggesting the absence of collinearity issues.

Table 2. Construct Reliability, Validity, and Collinearity Test Result

Dimension	Constructs, details of measures, and results of validity and reliability tests	Outer Loading	VIF
	<i>Industry 4.0 (AVE= 0.520, Rho_a = 0.873, CR = 0.896, CA =0.868)</i>	0.721	1.714
	The integration of Industry 4.0 technologies is crucial for the pharmaceutical industry, especially in terms of enhancing supply chain dynamics.	0.781	1.965
	I contend that the implementation of Industry 4.0 applications can significantly boost the efficiency of the pharmaceutical supply chain.	0.743	1.915
	Utilizing a diverse range of Industry 4.0 applications enhances our company's competitive advantage.	0.715	1.729
	Our employees have been trained to proficiently utilize Industry 4.0 applications.	0.735	1.712
	Our organization has embraced cutting-edge technologies, such as big data analytics, blockchain, artificial intelligence, and the Internet of Things.	0.751	1.944
	We have developed an effective risk management system powered by artificial intelligence.	0.667	1.714

	We have also created a robust financial control system based on blockchain technology.	0.721	1.645
	The implementation of Industry 4.0 applications enables effective management of the pharmaceutical industry's supply chain operations during crises, leveraging IoT and big data analytics.	0.721	1.496
	<i>Knowledge management (AVE= 0.516, Rho_a = 0.916, CR = 0.927, CA =0.915)</i>		
Knowl edge	Our organisation has clear rules for formatting or categorizing its product knowledge.	0.726	1.810
Acquis ition	Our organisation members use technology to search for new knowledge	0.749	2.304
(mean =4.00)	Our organisation members use technology to retrieve knowledge about its products and process	0.724	1.933
Knowl edge	Our organisation structure facilitates the discovery of new knowledge	0.677	1.606
Conve rsion	Our organisation facilitates knowledge exchange across functional boundaries	0.745	2.055
(mean =3,99)	Our organisation members are encouraged to interact with other groups.	0.695	1.843
	Our organisation members use technology to cooperate with other persons inside the organization.	0.717	1.964
	Our organisation members can understand not only their own tasks but also others' task	0.755	2.289
Knowl edge	Our organisation members can communicate well not only with their department members but also with other department members.	0.727	2.088
Applic ation			
(Mean = 3.994)			
Knowl edge	Our organisation has reward system for sharing knowledge.	0.664	1.769
Protec tion	Our organisation employees are readily accessible.	0.671	1.621
(Mean =4.02)	Our organisation members are specialists in their own part.	0.758	2.182
	<i>Transformational leadership (AVE= 0.619, Rho_a = 0.911, CR = 0.919, CA =0.898)</i>		
	Articulates a compelling vision of the supply chain future	0.767	2.150
	Elucidates the primary objective that drives the actions of all participants in the supply chain.	0.715	1.955
	Aims to gather diverse viewpoints from fellow members when addressing an issue.	0.787	2.498
	Encourages colleagues to examine challenges from various perspectives.	0.798	2.217
	Assists fellow members in cultivating their strengths in supply chain execution.	0.815	2.105
	Motivates other members to persistently enhance their skills related to the supply chain.	0.825	2.482
	Encourages other members to continually improve their supply chain skills	0.798	2.645
	<i>Sustainability performance (AVE= 0.584, Rho_a = 0.946, CR = 0.952, CA =0.945)</i>		
Econo mic	Over the past five years, our company has consistently achieved an average return on investment that surpasses the industry average.	0.757	2.232
Sustai		0.736	2.221

nability (Mean =3.99)	In terms of profitability, our company has maintained an average profit that exceeds the industry standard during the last five years.		
	Additionally, our company's profit growth has outpaced the industry average over the same five-year period.	0.791	2.530
	Our average sales profitability has also been higher than the industry average for the last five years.	0.722	2.093
	By adopting Industry 4.0 technologies, our company has successfully reduced energy consumption costs.	0.780	2.622
Social Sustainability (Mean =4.05)	Furthermore, our company has enhanced stakeholder well-being in comparison to competitors over the past five years.	0.757	2.158
	In terms of community health and safety, our company has made significant improvements relative to its competitors during the last five years.	0.730	2.133
	Our company has effectively minimized its environmental impact and associated risks to the public compared to competitors over the past five years.	0.778	2.412
	Our company has provided health and safety requirements for the employees to achieve sustainability	0.742	2.059
Environment Sustainability (Mean =4.02)	Our company has developed new products that reduces health risk for consumers to achieve sustainability by implementing industry 4.0	0.798	2.682
	Over the last five years, our company has successfully minimized waste and emissions from its operations in comparison to its competitors.	0.779	2.448
	In the past five years, our company has effectively lowered the environmental impact of its products and services when compared to its competitors.	0.791	2.556
	To attain sustainability, our company has decreased energy consumption through the adoption of Industry 4.0 technologies.	0.782	2.565
	Our company has also reduced material consumption to promote sustainability by leveraging Industry 4.0.	0.753	2.326

Table 3. Heterotrait-Monotrait Ratio (HTMT)

Variable	I4.0	KM	SP
I4.0			
KM	0.287		
SP	0.733	0.238	
TL	0.690	0.223	0.473

The findings illustrated in Table 3 reveal that all HTMT values remain beneath the critical threshold of 0.85, thereby affirming sufficient discriminant validity among the constructs. Additionally, the model exhibits an acceptable fit, as evidenced by SRMR values of 0.049 (saturated) and 0.052 (estimated), both of which are below the suggested threshold. Moreover,

the structural model accounts for 56.0% of the variance in sustainable performance ($R^2 = 0.560$), signifying considerable explanatory capability.

The results of hypothesis testing, as shown in Table 4, indicate that Industry 4.0 exerts a positive and statistically significant influence on sustainable performance ($\beta = 0.371$, $p < 0.001$), thereby supporting H1. Conversely, knowledge management does not exhibit a significant direct impact on sustainable performance ($\beta = 0.021$, $p = 0.305$), resulting in the rejection of H2. In terms of moderating effects, transformational leadership negatively moderates the relationship between Industry 4.0 and sustainable performance ($\beta = -0.069$, $p = 0.003$), suggesting that H3 is not supported in the anticipated direction. However, transformational leadership positively moderates the relationship between knowledge management and sustainable performance ($\beta = 0.057$, $p = 0.033$), thereby supporting H4.

Table 4: Hypothesis Testing Result

Path	Coefficient β	p -values	Results
Direct Effect			
H1 I4.0 \rightarrow SP	0.371	0.000	Supported
H2 KM \rightarrow SP	0.021	0.305	Not Supported
Moderating Effect			
H3 I4.0 x TL \rightarrow SP	-0.069	0.003	Not Supported
H4 KM x TL \rightarrow SP	0.057	0.033	Supported

Discussion

The findings indicate that Industry 4.0 implementation has a positive and significant effect on Sustainable Performance among pharmaceutical firms in Indonesia. This result underscores the role of digital capabilities as a key enabler of improved operational efficiency, process transparency, and data driven decision making quality, which jointly support economic, social, and environmental performance outcomes. From a Dynamic Capability View perspective, Industry 4.0 functions as a dynamic capability that enhances organisational sensing of environmental changes, enables seizing through the adoption of digital technologies, and supports transforming by restructuring and aligning internal resources and processes to remain adaptive to market dynamics and highly regulated operational requirements (Alyahya et al., 2023; Buhaya & Metwally, 2024; Tao & Chao, 2024; Vu et al., 2023).

Importantly, this direct effect suggests that digital capabilities in the pharmaceutical sector operate at the level of core operational routines rather than peripheral support functions. In highly regulated environments, digitalisation initiatives are embedded within validated processes, quality systems, and compliance frameworks. As a result, Industry 4.0 implementation not only enhances operational efficiency but also reinforces process reliability, traceability, and control. These improvements contribute directly to Sustainable Performance by reducing process deviations, material waste, rework, and operational disruptions, while ensuring consistent product quality and supply continuity. Through this mechanism, firms are able to simultaneously strengthen economic performance, minimize environmental inefficiencies, and safeguard social outcomes related to product safety and availability. This integrated role explains why Industry 4.0 demonstrates a robust and direct contribution to Sustainable Performance without requiring additional enabling mechanisms.

In contrast, Knowledge Management does not exhibit a direct and significant effect on Sustainable Performance. This finding suggests that the existence of Knowledge Management systems and practices does not automatically translate into value generating strategic capabilities. In the highly regulated and compliance driven pharmaceutical context, Knowledge Management practices tend to be oriented toward documentation, procedural standardisation, and regulatory compliance, thereby limiting their role to supporting operational legitimacy rather than strategic renewal. As a result, knowledge that has been acquired and codified is not fully translated into operational actions or strategic decision making processes that directly enhance Sustainable Performance (Dongo et al., 2025; Grant, 1996; Khan & Rauf, 2024).

This pattern indicates that knowledge in such contexts functions primarily as an institutional requirement rather than as a dynamic input for performance improvement. While codified knowledge is essential for audits, validation, and regulatory inspections, its strategic potential remains underutilized when it is decoupled from learning loops, cross functional

problem solving, and adaptive decision making. Under these conditions, knowledge does not translate into process improvement, resource optimisation, or risk mitigation, all of which are central mechanisms through which Sustainable Performance is achieved. Consequently, Knowledge Management remains a background capability whose value does not surface in economic, environmental, or social performance outcomes unless it is actively activated through organisational learning and managerial orchestration.

The role of Transformational Leadership in this study is explicitly situational and contingent. The empirical results show that Transformational Leadership significantly moderates the relationship between Industry 4.0 and Sustainable Performance, but in a negative direction, indicating that Transformational Leadership does not strengthen this relationship as hypothesised. This finding reflects a misalignment between a leadership style that emphasizes visionary change and value transformation and an organisational context that remains at a moderate level of readiness for Industry 4.0 adoption.

During the early stages of digital transformation, pharmaceutical organisations continue to rely heavily on process stability, procedural clarity, and operational control to meet regulatory demands and ensure supply continuity. Under such conditions, leadership approaches that overly emphasize value transformation and long term vision may disrupt operational discipline and increase implementation uncertainty, thereby weakening the effectiveness of Industry 4.0 initiatives (Chatterjee et al., 2022; Prakosa et al., 2024; Zhang et al., 2020). This result is consistent with Path Goal Theory, which posits that leadership effectiveness depends on the alignment between leadership behaviour, task characteristics, and follower readiness (House, 1971, 1996).

Conversely, Transformational Leadership is found to strengthen the relationship between Knowledge Management and Sustainable Performance. Through inspirational motivation, intellectual stimulation, and individualised consideration, Transformational Leadership encourages knowledge sharing, collective learning, and the translation of knowledge into productive operational actions (Akdere & Egan, 2020; Alhawamdeh et al., 2024; Żywiołek et al., 2022). This finding highlights that the strategic value of Knowledge Management is inherently latent and cannot be realized without leadership mechanisms that actively mobilize knowledge into coordinated organisational practice. In this sense, Transformational Leadership acts as a catalytic mechanism that converts static knowledge repositories into dynamic organisational learning processes. By fostering psychological safety, encouraging questioning of existing routines, and legitimising knowledge exchange across functional boundaries, Transformational Leadership enables Knowledge Management to move beyond compliance support toward performance relevant application.

A contrasting situation can be observed in pharmaceutical organisations that seek to improve cross-functional knowledge sharing among production, quality assurance, regulatory affairs, and supply chain departments. In these settings, knowledge often exists in separate functional silos and is primarily documented for compliance purposes. Transformational leaders can stimulate employees to share experiences, discuss process improvements, and collaboratively solve operational problems beyond formal documentation requirements. For instance, lessons learned from product deviations, audit findings, or supply disruptions can be transformed into organisational learning when leaders actively encourage communication and knowledge exchange across departments. Under these conditions, transformational leadership acts as a catalyst that converts accumulated knowledge into actionable improvements, thereby strengthening the contribution of knowledge management to sustainable performance.

Overall, the results reveal fundamentally different mechanisms through which Industry 4.0 implementation and Knowledge Management contribute to Sustainable Performance. Industry 4.0 operates as a dynamic capability that directly strengthens Sustainable Performance, whereas the contribution of Knowledge Management is indirect and conditional upon leadership alignment. The integration of Path Goal Theory provides further explanation by demonstrating that the effectiveness of Transformational Leadership is situational, such that misalignment between leadership style and organisational readiness may constrain the benefits of digital capabilities while simultaneously activating the strategic value of Knowledge Management.

Taken together, these findings emphasize that Sustainable Performance in regulated industries does not arise from the mere accumulation of organisational capabilities, but from their context specific orchestration. In this process, leadership plays a selective and enabling role rather

than a universally amplifying one. Transformational Leadership functions as a boundary condition that selectively enables or constrains the impact of organisational capabilities, thereby reinforcing the contingent nature of the relationship between capabilities and performance.

CONCLUSION

The main findings show that Industry 4.0 has a strong direct effect on sustainable performance, whereas knowledge management does not have a significant direct effect. In contrast, transformational leadership produces opposing moderating effects: it weakens the relationship between Industry 4.0 and sustainable performance while strengthening the relationship between knowledge management and sustainable performance. These results indicate that the effectiveness of organizational capabilities is not uniform but depends on their alignment with leadership approaches and organizational conditions. This study contributes to the Dynamic Capabilities View, the Knowledge-Based View, and Path-Goal Theory by demonstrating that organizational capabilities do not operate through a single pathway.

Industry 4.0 functions as a dynamic capability embedded in operational processes, consistent with the Dynamic Capabilities View, in which value is created through the integration and reconfiguration of resources. In contrast, knowledge management reflects the Knowledge-Based View, which maintains that knowledge does not automatically create value unless it is transformed into organizational capabilities. Furthermore, the findings extend Path-Goal Theory by showing that the effectiveness of transformational leadership is context-dependent and produces different outcomes depending on the nature of the capability and the stage of its implementation, particularly in regulated environments where process stability is critical. From a managerial perspective, the priority should be alignment rather than the mere accumulation of capabilities.

Managers should prioritize the effective implementation of Industry 4.0 through process stabilization, system integration, disciplined data use, and greater standardization across organizational boundaries. At the same time, they should ensure that knowledge management is translated into actionable processes, decision rules, and cross-functional practices. Leadership approaches should therefore be applied situationally, with an emphasis on process-oriented discipline during the early stages of digital implementation and transformational leadership when mobilizing knowledge through learning, sharing, and application. Such alignment can help ensure that digital and knowledge-based initiatives consistently contribute to sustainable performance.

This study is subject to several limitations. First, its cross-sectional research design restricts its ability to capture the dynamic evolution of digital capabilities, knowledge management practices, and leadership roles over time. Second, the use of self-reported survey data based on managerial perceptions may not fully reflect objective performance outcomes, despite the purposive selection of experienced respondents. Third, the empirical setting is limited to pharmaceutical manufacturing firms in Indonesia, and the highly regulated nature of this context may constrain the generalizability of the findings to other industries and institutional environments. In light of these limitations, future research should adopt longitudinal designs to examine how digital and knowledge-based capabilities, as well as leadership roles, evolve over time in shaping sustainable performance.

The use of mixed-method approaches and objective performance indicators would further strengthen the robustness of the findings by providing deeper insights into the mechanisms linking organizational capabilities and performance. In addition, cross-industry and cross-country comparative studies are recommended to improve understanding of the contextual and institutional factors that influence the relationships among Industry 4.0, knowledge management, leadership, and sustainable performance. Future research should also explore the applicability of these findings to other highly regulated sectors, such as food manufacturing, chemical processing, and healthcare services, in which operational constraints and compliance requirements similarly shape the effectiveness of digital and knowledge-based capabilities.

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AUTHOR CONTRIBUTION STATEMENT

Indah Kurniawaty conceptualized and designed the research, conducted the data analysis, and was responsible for writing the manuscript. Willy Arafah contributed to the methodology, supervised the data collection process, and provided critical revisions to the manuscript. Wahyuningsih Santosa contributed to data preparation, performed the statistical modeling, and assisted in writing the results and discussion sections. All authors approved the final manuscript for submission.

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