

Artificial Intelligence-Enabled Supply Chain Competency as a Driver of Bio-Circular-Green (BCG) Sustainability Performance: Empirical Evidence from Thailand

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Abstract: This study investigates the structural role of Artificial Intelligence (AI) utilization in enhancing supply chain competency and Bio-Circular-Green (BCG) sustainability performance among organizations in Chiang Rai Province, Thailand. A quantitative survey was conducted with 400 respondents using structured questionnaires. Reliability testing indicated excellent internal consistency (Cronbach's alpha = 0.96). Descriptive statistics, correlation analysis, and regression modeling were applied. Results show moderate AI utilization across SCOR processes, with the highest adoption in planning and the lowest in delivery operations. Supply chain competency was moderate overall, while BCG performance outcomes were high, particularly in environmental performance. Regression analysis confirms that AI utilization significantly influences supply chain competency ($\beta = 0.889$, $p < 0.001$), which in turn significantly influences BCG outcomes ($\beta = 0.882$, $p < 0.001$). The findings support a competence-mediated pathway in which AI adoption strengthens operational capabilities that subsequently drive sustainability performance. The study contributes empirical evidence to engineering management literature by demonstrating how AI-enabled digital transformation supports regional sustainable development strategies.

Keywords: Artificial Intelligence, BCG Economy, Digital Transformation, Supply Chain Competency, Sustainability Performance

1. Introduction

Thailand's economic strategy increasingly emphasizes sustainable development through the Bio-Circular-Green (BCG) model, which integrates bio-based resource utilization, circular production systems, and environmentally responsible growth. Under this framework, organizations are expected to improve economic competitiveness while simultaneously reducing environmental impact and enhancing social value. Achieving these objectives requires not only policy direction but also operational transformation at the organizational level, particularly within supply chain systems that coordinate sourcing, production, distribution, and reverse logistics activities.

Regional economies such as Chiang Rai Province present unique structural challenges. The province integrates agriculture, agro-processing, manufacturing, tourism, and service industries, resulting in multi-tiered supply chains characterized by demand uncertainty, seasonal variability, small and medium-sized enterprises (SMEs), and fragmented information systems. These characteristics increase coordination complexity and reduce operational efficiency. Inefficiencies in forecasting, supplier integration, logistics routing, and inventory control can directly affect cost performance, service reliability, and environmental outcomes. Therefore, improving supply chain capability is a strategic requirement for regional sustainable development.

Artificial Intelligence (AI) has emerged as a critical engineering enabler for digital supply chain transformation. AI-based systems support demand forecasting through predictive analytics, enhance supplier selection using data-driven evaluation models, optimize production scheduling through algorithmic planning, and improve logistics routing via dynamic path optimization. In addition, AI improves traceability and transparency by integrating real-time data across supply chain nodes. Previous studies confirm that AI adoption increases operational efficiency, reduces uncertainty, and enhances decision-making quality [1], [2]. These capabilities are particularly relevant to BCG objectives, where resource optimization, waste reduction, and carbon footprint minimization are central performance indicators.

Despite growing interest in AI adoption, empirical evidence remains limited regarding how AI contributes to sustainability performance through the mediating mechanism of supply chain competency. Most prior research examines either technological adoption or sustainability outcomes independently, without integrating both constructs within a single analytical framework. Furthermore, regional-level investigations in emerging economies are scarce, leaving a gap in understanding how AI-enabled operational capability translates into measurable BCG outcomes.

2. Methodology

A quantitative survey design was applied. The population comprised employed individuals in Chiang Rai Province (600,469 persons) [3]. Using Yamane's formula [4], 400 respondents were selected.

The questionnaire measured:

- (1) AI utilization in SCOR processes (Plan, Source, Make, Deliver, Return),

- (2) Supply chain capability (efficiency, flexibility, transparency),
- (3) BCG sustainability performance (economic, social, environmental).

Content validity was confirmed by expert review. Reliability testing yielded Cronbach’s alpha = 0.96. Data were analyzed using descriptive statistics, Pearson correlation, and linear regression.

This study addresses this gap by examining whether AI utilization enhances supply chain competency and whether such competency subsequently leads to improved BCG sustainability performance in Chiang Rai Province. By empirically analyzing the relationships among AI adoption, operational capability, and sustainability outcomes, this research contributes to engineering management literature and provides evidence-based insights for regional digital transformation strategies.

3. Results

3.1 AI Utilization across SCOR Processes

Table 1: AI Utilization in Supply Chain Management (SCOR Framework)

Process	Mean	S.D.	Interpretation
Digital Readiness	2.93	0.94	Moderate
Plan	3.21	0.92	Moderate (Highest)
Source	3.09	0.96	Moderate
Make	3.09	1.02	Moderate
Deliver	3.02	1.04	Moderate (Lowest)
Return	3.04	1.17	Moderate

AI adoption was moderate across all SCOR dimensions. The planning function demonstrated the strongest integration of AI tools, particularly in demand forecasting and customer analytics. The delivery stage showed the lowest adoption, indicating limited AI utilization in logistics routing and real-time tracking.

3.2 Supply Chain Capability

Table 2: Supply Chain Capability Dimensions

Dimension	Mean	S.D.	Level
Operational Efficiency	3.21	1.02	Moderate (Lowest)
Flexibility & Responsiveness	3.30	1.09	Moderate
Transparency & Traceability	3.31	1.03	Moderate (Highest)
Overall Mean	3.27	1.02	Moderate

Transparency and traceability achieved the highest score, reflecting improved monitoring and information visibility. Operational efficiency remained comparatively lower, suggesting that AI integration has not yet fully translated into measurable cost reductions.

3.3 BCG Sustainability Performance

Table 3: BCG Performance Outcomes

Dimension	Mean	S.D.	Level
Economic	3.43	1.09	High
Social	3.38	1.04	Moderate
Environmental	3.48	1.04	High (Highest)
Overall Mean	3.43	1.03	High

Environmental performance showed the strongest outcome, indicating that traceability and process transparency contribute significantly to sustainability objectives.

3.4 Correlation Analysis

Table 4: Pearson Correlation Matrix

Variables	AI Utilization	Supply Chain Capability	BCG Performance
AI Utilization	1	0.889**	0.824**
Supply Chain Capability	0.889**	1	0.882**
BCG Performance	0.824**	0.882**	1

All variables show strong positive correlations ($r > 0.80$), indicating high structural association among constructs.

3.5 Regression Analysis

Model 1: AI → Supply Chain Capability

$$\beta = 0.889$$

$$R = 0.889$$

$$R^2 = 0.790$$

$$F = 1451.738$$

$$p < 0.001$$

AI explains 79% of the variance in supply chain capability.

Model 2: Supply Chain Capability → BCG Performance

$$\beta = 0.882$$

$$R = 0.882$$

$$R^2 = 0.778$$

$$F = 1350.719$$

$$p < 0.001$$

Supply chain capability explains 77.8% of the variance in BCG sustainability performance.

4. Discussion

The results indicate that AI utilization contributes significantly to strengthening operational transparency, responsiveness, and functional integration across supply chain processes. Organizations that adopt AI-based tools for forecasting, supplier evaluation, and data analytics demonstrate improved visibility of information flows and enhanced coordination among supply chain partners. These operational improvements reduce uncertainty, support evidence-based decision-making, and improve process consistency. As a result, AI-driven capability functions as an enabling mechanism that converts digital investment into measurable sustainability outcomes aligned with BCG objectives.

Although the overall level of AI adoption remains moderate, the relatively high environmental performance observed in this study suggests that even partial digital integration can generate meaningful sustainability benefits. In particular, traceability and transparency systems supported by AI appear to play a crucial role in monitoring resource utilization, reducing waste, and lowering environmental impact. These systems improve data accuracy and facilitate compliance with environmental standards, thereby strengthening green performance indicators. However, the delivery stage continues to represent a structural bottleneck. Limited AI integration in logistics routing, real-time tracking, and last-mile optimization constrains cost efficiency and responsiveness. Addressing this gap through advanced logistics algorithms and real-time data integration is essential for achieving full supply chain optimization and long-term sustainable competitiveness under the BCG framework.

5. Conclusion

This study confirms that AI-enabled supply chain capability plays a significant role in enhancing BCG sustainability performance. The empirical results demonstrate that AI adoption strengthens core operational structures—particularly transparency, traceability, and responsiveness which subsequently translate into improved environmental and economic outcomes. By improving forecasting accuracy, data integration, and process coordination, AI supports resource efficiency and reduces operational waste, thereby aligning organizational performance with BCG strategic objectives.

From a managerial perspective, the findings suggest that organizations should prioritize AI integration in logistics and delivery operations, where adoption remains comparatively low. Emphasis should also be placed on strengthening data governance frameworks to ensure data accuracy, interoperability, and security across supply chain nodes. In addition, continuous workforce development in digital analytics and AI applications is essential to maximize the effectiveness of technological investment and ensure sustainable capability building.

Future research may apply structural equation modeling to examine mediation effects more rigorously and to test alternative causal pathways among AI utilization, operational capability, and sustainability performance. Comparative studies across regions or industries could further enhance the generalizability of the findings.

References

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