FACTORS INFLUENCING THE ADOPTION OF GREEN LOGISTICS IN MANUFACTURING ENTERPRISES : A PLS-SEM APPROACH FROM THAI NGUYEN PROVINCE

Pham Thi Thanh Mai[1], Nguyen Manh Hung[2*] and Le Duc Anh[3]

[1] Faculty of Business and Logistics, Thai Nguyen University of Economics and Business Administration, Thai Nguyen University, Thai Nguyen, Vietnam

[2] Thai Nguyen University, Thai Nguyen, Vietnam

[3] Student of Thai Nguyen University of Economics and Business Administration, Thai Nguyen University, Thai Nguyen, Vietnam

Abstract

Green logistics plays a pivotal role in advancing sustainable supply chains, yet its uptake in emerging economies remains uneven. This study explores the determinants of green logistics adoption among manufacturing enterprises in Thai Nguyen province, Vietnam, a growing industrial hub with strong foreign investment and increasing sustainability commitments. Drawing upon the Theory of Planned Behavior (TPB) and the Technology–Organization–Environment (TOE) framework, the research model tests the effects of environmental–social awareness (ENV), external pressure (EXT), cost–effectiveness perception (ECO), internal capabilities (INT), and technological infrastructure (TEC) on the adoption of green logistics (USE). Survey data were collected from 30 enterprises (60 valid responses) and analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The results indicate that ENV, ECO, EXT, and TEC exert significant positive impacts on USE, while INT shows no significant effect. Moreover, EXT also indirectly affects USE through ENV, highlighting a partial mediation mechanism. The model explains 63.8% of the variance in green logistics adoption, demonstrating substantial explanatory power. These findings theoretically validate the integration of TPB and TOE in a provincial manufacturing context, while practically suggesting that raising environmental awareness, enhancing perceptions of cost-effectiveness, strengthening technological infrastructure, and leveraging institutional pressures are crucial levers to accelerate green logistics adoption in emerging economies.

Research purpose:
The purpose of this study is to examine the factors that influence manufacturing enterprises in Thai Nguyen province to adopt green logistics. Specifically, the research evaluates the direct and indirect effects of environmental–social awareness (ENV), external pressures (EXT), cost-effectiveness perception (ECO), internal capability (INT), and technological infrastructure (TEC) on the decision to adopt green logistics (USE). By testing this model with firm-level data, the study provides empirical evidence clarifying both organizational and contextual drivers of sustainable logistics adoption.

Research motivation:
While green logistics has been widely studied in developed economies, provincial-level research in emerging contexts remains limited. Thai Nguyen province offers a dynamic case: it is a key industrial hub with a growing number of domestic and foreign-invested manufacturers, yet the adoption of green logistics practices is still uneven and underexplored. Understanding what drives or constrains local firms is essential for designing effective interventions aligned with Vietnam's national green growth strategy. This research is motivated by the need to bridge this empirical gap at the sub-national level and to generate actionable insights that advance both theory and practice.

Research design, approach, and methods:
This study employs a quantitative, cross-sectional design grounded in the TPB and TOE frameworks. Data were collected via a structured questionnaire administered to 30 manufacturing enterprises in Thai Nguyen, yielding 60 valid responses (two per firm). All constructs were measured on five-point Likert scales adapted from established studies. The proposed model was tested using Partial Least Squares Structural Equation Modeling (PLS-SEM), a variance-based method well-suited for small to medium samples and exploratory research. The analysis was conducted in two stages: (i) assessment of the measurement model (reliability, convergent validity, discriminant validity), and (ii) evaluation of the structural model (path coefficients, R^2, Q^2, effect sizes, and mediation effects via bootstrapping with 2,000 resamples).

Main findings:
The PLS-SEM results reveal that environmental–social awareness (ENV), cost-effectiveness perception (ECO), and technological infrastructure (TEC) exert significant positive impacts on green logistics adoption (USE). External pressure (EXT) also has a direct positive effect on USE and an indirect effect through ENV, confirming a partial mediation mechanism. By contrast, internal capability (INT) does not show a statistically significant influence. The model explains approximately 63.8% of the variance in adoption, indicating substantial explanatory power.

Practical/managerial implications:

The findings suggest that managers should focus on strengthening environmental awareness within the workforce and enhancing perceptions of cost-effectiveness to motivate green logistics adoption. Investments in technological infrastructure are critical enablers, while external institutional pressures can be leveraged to reinforce environmental–social awareness. Policymakers and local authorities can accelerate adoption by reducing cost barriers through targeted incentives, promoting exemplary success cases, and creating supportive regulatory frameworks. Collaboration among enterprises, government, and local communities is vital to scale up green logistics practices in industrial provinces such as Thai Nguyen.

Keywords: green logistics, PLS-SEM, manufacturing enterprises, adoption decision, sustainability, Thai Nguyen province

1. INTRODUCTION

The transition toward sustainable development has become a pressing global challenge, with logistics playing a pivotal role in reducing environmental impacts across supply chains. Green logistics, which integrates environmental considerations into activities such as transportation, warehousing, and packaging, has been recognized not only as an environmental imperative but also as a driver of efficiency, innovation, and competitiveness. As global customers, governments, and communities increasingly demand sustainable practices, manufacturing enterprises are under rising pressure to adopt green logistics strategies.

Vietnam, one of the fastest-growing economies in Southeast Asia, has made sustainability a key component of its industrial policy. Thai Nguyen province, in particular, has emerged as a strategic industrial hub, characterized by a strong information technology foundation, rapid foreign direct investment, and significant import-export activities. Local authorities and enterprises alike have expressed growing interest in green transformation. Despite these favorable conditions, the degree to which manufacturing firms in Thai Nguyen adopt green logistics and the determinants of such decisions remain insufficiently understood.

Previous studies have applied frameworks such as the Theory of Planned Behavior (TPB) and the Technology-Organization-Environment (TOE) model to explain organizational adoption of green practices. Findings suggest that environmental-social awareness, external pressures, cost-benefit considerations, internal capabilities, and technological readiness are critical drivers. However, most empirical evidence comes from developed economies or nationwide surveys, leaving a lack of in-depth analysis at the provincial level in emerging economies.

Research gap and purpose. While green logistics adoption has been widely studied, little attention has been paid to how these factors operate within specific industrial clusters in Vietnam. This study addresses this gap by examining the determinants of green logistics adoption among manufacturing enterprises in Thai Nguyen province using PLS-SEM. The findings aim to enrich theoretical understanding of green logistics adoption in emerging contexts and provide practical recommendations for managers and policymakers seeking to accelerate sustainable logistics development.

2. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

2.1 Literacy review

2.1.1. Green logistics and its significance

Green logistics refers to the integration of environmental considerations into logistics operations, aiming to reduce emissions, optimize resource use, and promote sustainability across supply chains. Beyond ecological benefits, green logistics enhances efficiency, corporate reputation, and regulatory compliance (Zhu & Sarkis, 2004). Recent studies emphasize its growing role in meeting global sustainability goals and supporting long-term competitiveness, particularly in emerging markets such as Vietnam, where industrialization and sustainability transitions occur simultaneously (González-Torre et al., 2021).

2.1.2. Theoretical frameworks for adoption behavior

Two well-established frameworks inform the study of green logistics adoption. The Theory of Planned Behavior (TPB) posits that behavioral intention is shaped by perceived benefits, social norms, and perceived control (Ajzen, 1991). In

parallel, the Technology Organization Environment (TOE) framework highlights how technological readiness, organizational resources, and environmental context shape innovation adoption (Tornatzky & Fleischer, 1990). These frameworks remain relevant in explaining sustainability-oriented decisions, particularly in logistics, where both organizational intention (TPB) and contextual readiness (TOE) jointly shape adoption behavior (Dubey et al., 2022) and provide the conceptual basis for this study.

2.1.3. Key factors influencing green logistics adoption

Empirical studies consistently identify several drivers of adoption. Environmental-social awareness (ENV) fosters proactive decisions as firms recognize their responsibility and potential reputational benefits (Pan et al., 2019). External pressures (EXT) from governments, customers, and competitors serve as strong motivators, especially in regulated markets (Kobashi et al., 2021). Perceived cost-effectiveness (ECO) reflects firms' evaluation of financial feasibility, balancing short-term costs and long-term gains (Zhu & Sarkis, 2004). Internal capabilities (INT), such as skilled human resources and supportive organizational culture, are often theorized to strengthen firms' readiness to adopt (Yadav et al., 2020). However, empirical findings remain mixed, with some contexts showing limited or insignificant effects, particularly among small and medium-sized enterprises in emerging provinces. Finally, technological infrastructure (TEC), including digital platforms, IoT, and Industry 4.0 applications, facilitates efficient implementation of green logistics (Bag et al., 2021; Kamble et al., 2023).

2.1.4. Empirical evidence from emerging economies

In emerging economies, adoption patterns are shaped by institutional voids, financial constraints, and uneven technological readiness. Studies in China, India, and ASEAN countries highlight both the opportunities of digital transformation and the barriers of cost and policy enforcement (Mishra et al., 2021; Liu et al., 2022). Vietnam's logistics sector has begun aligning with global standards, yet provincial-level empirical evidence remains scarce. In Vietnam, while national-level studies have started to emerge, there is a lack of provincial-level evidence that captures the diversity of industrial clusters such as Thai Nguyen. Thai Nguyen, as an industrial province, presents a unique case for examining how contextual factors interact with organizational decisions.

2.1.5. Research gap and contribution

Although green logistics has received increasing scholarly attention, most prior studies emphasize national-level analyses or focus on developed economies. There is limited empirical research exploring how internal capabilities, technological readiness, and external pressures jointly influence adoption in specific industrial clusters of emerging markets. This study addresses the gap by applying PLS-SEM to firm-level survey data from manufacturing enterprises in Thai Nguyen province. Theoretically, it validates TPB and TOE frameworks in a provincial emerging-economy context, while also providing nuanced evidence that internal capabilities may play a limited role, and that external pressures operate indirectly through environmental awareness. Practically, it offers actionable insights for managers and policymakers to strengthen environmental–social awareness, reduce cost barriers, and develop technological infrastructure to foster green logistics adoption at the regional level.

2.2 Hypothesis development

+ Independent variables (influencing factors):

Variable ENV: Environmental–social awareness

Variable EXT: External pressure (customers, policies, competitors)

Variable ECO: Cost-effectiveness perception

Variable INT: Internal capacity of the enterprise (resources, policies)

Variable TEC: Infrastructure - supporting technology at the locality/enterprise

+ Dependent variables: Variable USE: Decision to use green logistics

+ Research hypotheses:

Environmental–social awareness (ENV) and adoption of green logistics

Environmental awareness has been consistently recognized as a central driver of sustainable behavior in organizations. When managers perceive clear benefits such as reducing emissions, fulfilling corporate social responsibility, and enhancing reputation, they are more willing to invest in green logistics (Pan et al., 2019). In emerging economies, growing societal concern for sustainability further strengthens this awareness (Mishra et al., 2021).

H1. Environmental–social awareness (ENV) has a positive effect on the adoption of green logistics (USE).

External pressures (EXT) and adoption of green logistics

Government regulations, customer demands, and competitive dynamics create strong external pressure on firms to adopt sustainability practices. Prior research shows that coercive, normative, and mimetic pressures can accelerate the adoption of green logistics across different industries (Kobashi et al., 2021; Liu et al., 2022).

H2. External pressures (EXT) have a positive effect on the adoption of green logistics (USE).

Perceived cost-effectiveness (ECO) and adoption of green logistics

Financial considerations play a pivotal role in shaping adoption decisions. Firms tend to adopt green logistics when they perceive clear cost savings, efficiency gains, or long-term economic returns that outweigh initial investment costs (Zhu & Sarkis, 2004; Yadav et al., 2020).

H3. Perceived cost-effectiveness (ECO) has a positive effect on the adoption of green logistics (USE).

Internal capabilities (INT) and adoption of green logistics

The implementation of green practices requires adequate internal resources, including managerial commitment, skilled personnel, and a supportive organizational culture. Studies highlight that firms with stronger internal capabilities are better positioned to integrate sustainability practices into logistics (Bag et al., 2021).

H4. Internal capabilities (INT) have a positive effect on the adoption of green logistics (USE).

Technological infrastructure (TEC) and adoption of green logistics

Technological readiness provides the necessary foundation for implementing green logistics solutions such as digital platforms, real-time tracking, and automation. Investments in ICT and Industry 4.0 technologies reduce uncertainty and increase firms' confidence in adopting sustainable practices (Kamble et al., 2023).

H5. Technological infrastructure (TEC) has a positive effect on the adoption of green logistics (USE).

Mediation of environmental–social awareness in the EXT–USE relationship

While external pressures may not always lead directly to adoption, they often increase firms' awareness of environmental and social responsibilities. This heightened awareness can then drive actual adoption decisions (Dubey et al., 2022). Accordingly, environmental–social awareness is expected to mediate the relationship between external pressures and adoption.

H6. External pressures (EXT) indirectly influence green logistics adoption (USE) through environmental–social awareness (ENV).

3. METHODOLOGY

3.1 . Information collection and data processing method

Collect secondary information: Documents and secondary data are referenced from sources such as: Research published in scientific journals, scientific topics, theses, reports of the Thai Nguyen Department of Industry and Trade, Department of Planning and Investment, Thai Nguyen Provincial Statistics Office, etc., and other specialized reports.

Collect primary information: Interview and survey representatives of some manufacturing enterprises in Thai Nguyen province. The study used the method of collecting survey information and interviewing individuals working at manufacturing enterprises in the province. The study used the PLS-SEM model (Partial Least Squares Structural Equation Modeling). PLS-SEM is used to estimate model parameters based on the variance matrix. According to Hair & colleagues (2016), PLS-SEM applies ordinary least squares regression (OLS) with the goal of minimizing errors (ie, residual variance) of dependent variables. Or PLS-SEM estimates coefficients (path model relationships) to maximize the R^2 value of the dependent variable (target variable). PLS-SEM does not necessarily use a large sample size like CB-SEM. PLS-SEM uses a minimum sample size of 10 times the largest formative observer measured for a concept or 10 times the largest number of paths affecting a concept in the model (Barclay et al., 1995). Since the study identified 6 formative observers (6 paths), the minimum sample size of the study was 6x10 = 60 samples. Primary data collection and analysis were conducted by randomly selecting 60 managers representing 30 manufacturing enterprises in Thai Nguyen province for direct interviews and online surveys via Google Form.

Sampling method: The study employed a quantitative research design using a structured questionnaire survey to collect data from enterprises in Thai Nguyen province. A total of 60 valid responses were collected from 30 enterprises operating in manufacturing and service sectors. Although the sample size is relatively modest, it is considered acceptable for exploratory studies, particularly when applying PLS-SEM, which is suitable for small to medium sample sizes. Similar sample sizes have been used in prior exploratory studies in comparable contexts. The respondents were primarily logistics managers, environmental officers, and department heads who were directly involved in green logistics decision-making within their organizations. Approximately 60% held managerial positions, and the average work experience among respondents was around eight years. This ensures that the data were collected from knowledgeable and relevant informants

within each enterprise, thereby enhancing the reliability of the responses. The questionnaire was developed based on the results of the institutional research project code: CS2024-BA-02 conducted at the Thái Nguyen University of Economics and Business Administration – Thai Nguyen University. The measurement items were adapted from validated scales in previous studies (e.g., Ajzen, 1991; Tornatzky & Fleischer, 1990; Zhu & Sarkis, 2004) and then refined to fit the specific research context of Vietnamese enterprises. The questionnaire was reviewed by academic experts and pre-tested with a small group of managers to ensure clarity, contextual relevance, and content validity. All items were measured using a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree").

Software used: Data analysis was performed using SmartPLS version 4.0, which is widely adopted for PLS-SEM applications. SmartPLS allows simultaneous estimation of measurement and structural models and is suitable for small to medium sample sizes and complex models with mediating relationships. Descriptive statistics and preliminary checks (e.g., skewness, kurtosis, correlations) were conducted using SPSS version 23.0 to ensure data quality prior to structural analysis.

3.2 Research model

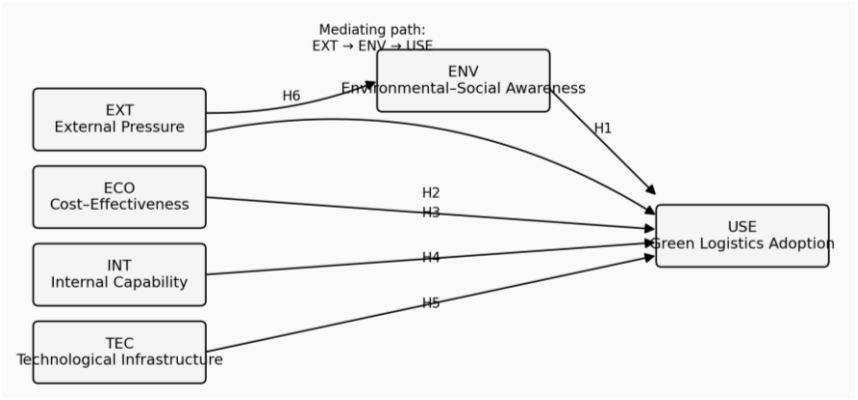


Fig. 1. Research model

Source: Research team proposal

3.3 Measurement matrix structure

To operationalize the latent variables in this study, each construct was measured using multiple reflective indicators adapted from prior research and adjusted to fit the local context. All items were assessed on a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"). Table 1 presents the measurement matrix structure, including the constructs, item codes, observed indicators, and their theoretical sources.

Table 1. Measurement matrix structure

Late variable	Code	Observed indicator
ENV – Environmental–social awareness	ENV1	Green logistics helps reduce environmental pollution
	ENV2	Green logistics improves corporate reputation
	ENV3	Green logistics demonstrates corporate social responsibility
EXT – External pressure	EXT1	Customers demand green logistics activities
	EXT2	Competitors adopt green logistics practices
	EXT3	Government policies and regulations promote green logistics
ECO – Perceived cost–effectiveness	ECO1	Green logistics helps reduce logistics costs
	ECO2	Creates long-term competitive advantage
	ECO3	Initial investment costs are acceptable
INT – Internal capabilities	INT1	The enterprise has the capacity to implement green logistics
	INT2	Human resources are capable of supporting green logistics
	INT3	There are specific policies/programs to support green logistics
TEC – Technological infrastructure	TEC1	Local infrastructure supports green logistics
	TEC2	Availability of modern technology for green logistics
	TEC3	Ability to access green logistics technology from external sources
USE – Adoption of green logistics (dependent variable)	USE1	The enterprise applies at least one green logistics activity
	USE2	The enterprise has plans to expand green logistics practices
	USE3	Green logistics is integrated into the enterprise's development strategy

Source: Research team proposal

4. RESULTS AND DISCUSSION

4.1 Descriptive statistics of the scale

Before testing the measurement and structural models, descriptive statistics were computed to provide an overview of the data distribution for each construct. These statistics also help identify potential variations across constructs and assess whether the data meet basic assumptions for subsequent PLS-SEM analysis.

Table 2. Descriptive statistics of the scales (n = 60)

Latent variable	Average value	Standard deviation	Min	Max	Interpretation
ENV (Environmental and Social Benefits Awareness)	3.43	1.14	1	5	Awareness is relatively high, but varies significantly among enterprises
TEC (Infrastructure – supporting technology)	3.51	1.17	1	5	Technology infrastructure is quite strong, though uneven across firms
INT (Internal Enterprise Capability)	3.49	1.09	1	5	Intrinsic capacity is moderate, not yet a decisive strength
ECO (Cost-effectiveness awareness)	3.44	1.14	1	5	Awareness of cost–benefit is fairly good, with some fluctuation
EXT (External Pressure)	3.42	1.13	1	5	Institutional/market pressure is present but moderate
USE (Green Logistics Use Decision)	3.49	1.19	1	5	Readiness to adopt green logistics is quite positive, but not uniform

Source: Summary of survey results by research team

The descriptive statistics results show that the scales in the model all have average values ranging from 3.4 to 3.5, indicating that the perception and behavior of enterprises toward green logistics are generally above the midpoint of the scale. In particular, TEC (3.51) and USE (3.49) have slightly higher average values, suggesting that the technological infrastructure and readiness to adopt green logistics are relatively favorable conditions in Thai Nguyen. INT (3.49) is also at a moderate-to-high level, showing that internal capabilities are present but not yet a decisive strength. Meanwhile, ENV (3.43) and ECO (3.44) reveal that awareness of environmental–social benefits and cost-effectiveness, although fairly positive, is still uneven across enterprises. EXT (3.42) indicates that institutional and market pressures exist, but remain only moderate. The relatively high standard deviations (≈1.1) across all constructs reflect substantial variation between enterprises. This implies that, despite encouraging signs, there is still considerable room for enhancing awareness and strengthening commitment to green logistics adoption in the local business community.

4.2. Data Check

Before conducting the PLS-SEM analysis, the survey data set was screened for completeness and reliability. The screening process revealed no missing values in the 60 valid responses. This reflects the good quality of data collection and allows the entire data set to be used for analysis without interpolation or observation removal. The data were tested for distribution through skewness and kurtosis. The results showed that the values were all within ±2, indicating that the data were close to a normal distribution, consistent with the assumption when applying PLS-SEM. The Pearson correlation coefficient matrix between independent variables was calculated to detect the possibility of multicollinearity. The results showed that all correlation coefficients were less than 0.8, thereby limiting the risk of serious multicollinearity in the structural model.

Table 3. Tests for data distribution (Skewness and Kurtosis)

Latent variable	Skewness	Kurtosis	Evaluate
ENV	-0.14	-0.97	Near normal distribution
TEC	-0.37	-0.64	Near normal distribution
INT	-0.37	-0.14	Near normal distribution
ECO	-0.20	-0.54	Near normal distribution
EXT	-0.36	-0.64	Near normal distribution
USE	-0.71	-0.34	Near normal distribution

Source: Summary of survey results by research team

The survey data meet the requirements of completeness, near-normal distribution and no serious multicollinearity problems, ensuring conditions for PLS-SEM analysis in the next steps.

Table 4. Pearson correlation matrix between independent variables

Variable	ENV	EXT	ECO	INT	TEC
ENV	-	0.60	-0.19	-0.08	-0.07
EXT	0.60	-	-0.03	-0.04	-0.06

ECO	-0.19	-0.03	-	0.26	0.09
INT	-0.08	-0.04	0.26	-	0.01
TEC	-0.07	-0.06	0.09	0.01	-

Source: Summary of survey results by research team

Table 4 presents the Pearson correlation coefficients among the independent latent variables (ENV, EXT, ECO, INT, and TEC). The results show that all correlation values are below the conservative threshold of 0.80, suggesting the absence of severe multicollinearity. The highest correlation is observed between ENV and EXT (r = 0.60), which is moderate and theoretically consistent, as external pressures are expected to foster greater environmental–social awareness. Other correlations range from weak to low-moderate, with some near-zero or slightly negative values, indicating that the constructs capture distinct dimensions of the drivers of green logistics adoption. Overall, the correlation analysis confirms that the independent variables can be simultaneously included in the structural model without risk of multicollinearity bias.

4.3. Measurement Model Evaluation

+ Reliability and convergent validity:

To ensure the adequacy of the measurement model, reliability and convergent validity were first assessed. Internal consistency was examined using Cronbach's Alpha and Composite Reliability (CR), with threshold values of 0.70 indicating acceptable reliability (Hair et al., 2022). Convergent validity was evaluated by examining the standardized outer loadings of each indicator and the Average Variance Extracted (AVE) for each construct, with loadings above 0.70 and AVE above 0.50 considered satisfactory.

Table 5. Reliability and convergent validity

Latent variable	Cronbach's Alpha	Composite Reliability (CR)	AVE
ENV	0.96	0.98	0.93
TEC	0.96	0.98	0.93
INT	0.89	0.93	0.82
ECO	0.96	0.97	0.92
EXT	0.95	0.97	0.92
USE	0.96	0.97	0.93

Source: Summary of survey results by research team

All Cronbach's Alpha > 0.7; CR > 0.7 and AVE > 0.5. proving that the scales have high reliability and convergent validity.

+ Discriminant validity:

In addition to reliability and convergent validity, discriminant validity was assessed to confirm that each construct is empirically distinct from the others. The Fornell–Larcker criterion was applied by comparing the square root of the AVE for each construct with its correlations with other constructs. Discriminant validity is established when the AVE's square root exceeds the corresponding inter-construct correlations (Fornell & Larcker, 1981).

Table 6. Discriminant validity

	ENV	TEC	INT	ECO	EXT	USE
ENV	0.97	-0.06	-0.04	-0.03	0.60	0.97
TEC	-0.06	0.96	0.01	0.09	-0.07	-0.06
INT	-0.04	0.01	0.91	0.26	-0.08	-0.04
ECO	-0.03	0.09	0.26	0.96	-0.19	-0.03
EXT	0.60	-0.07	-0.08	-0.19	0.96	0.60
USE	0.97	-0.06	-0.04	-0.03	0.60	0.97

Source: Summary of survey results by research team

According to the Fornell–Larcker criterion. the square root value of AVE (in bold on the diagonal) is greater than the correlation coefficient with other variables. confirming that the scales have discriminant validity.

The above results show that the measurement model in the study ensures reliability. convergent validity and discriminant validity. serving as the basis for the structural model analysis step.

4.4. Structural Model Evaluation and Hypothesis Testing

+ Structural Model Evaluation

The results indicate that the coefficient of determination for USE is $R^2 = 0.638$, meaning that the independent variables (ENV, EXT, ECO, INT, TEC) collectively explain approximately 63.8% of the variance in the decision to adopt green

logistics. This represents a substantial level of explanatory power for research in the management and organizational behavior domain. In addition, the positive Q^2 value demonstrates that the model possesses predictive relevance.

Regarding the relative contributions of the predictors, awareness of environmental and social benefits (ENV) emerges as the most influential factor, underscoring the critical role of environmental awareness in shaping adoption behavior. Technological infrastructure (TEC) and cost-effectiveness perception (ECO) also show significant positive impacts, highlighting the enabling role of digital platforms and financial feasibility in promoting green logistics. External pressure (EXT) exerts both a direct positive effect and an indirect effect via ENV, indicating that institutional and market pressures become more effective when enterprises internalize the environmental and social value of green practices. In contrast, internal capability (INT) does not have a statistically significant direct effect, reflecting that many firms in the province have not yet developed sufficient internal resources to independently drive adoption.

These findings suggest that raising environmental awareness, strengthening technological infrastructure, and addressing cost concerns are essential to accelerating the adoption of green logistics in Thai Nguyen. External pressures, while important, must be accompanied by effective communication and capacity-building efforts to ensure that enterprises recognize and act upon the long-term sustainability benefits.

+ Testing hypotheses

Hypotheses are tested by examining the sign and statistical significance of the path coefficient (β) in the structural model. A hypothesis is supported when the β coefficient has the correct sign as expected by theory and the p-value is < 0.05. For the mediation hypothesis (such as H6), the indirect effect is tested by bootstrapping 2.000 samples, and the hypothesis is accepted when the 95% confidence interval (CI) does not contain the value 0. The results are summarized in the Table below.

Table 7. Structural model estimation results (Path Coefficients)

Path	Beta	SE	t	p (boot)	CI 2.5%	CI 97.5%
EXT → ENV	0.59	0.10	5.74	0.00	0.39	0.80
ENV → USE	0.30	0.12	2.60	0.01	0.07	0.52
EXT → USE	0.38	0.11	3.33	0.00	0.16	0.60
ECO → USE	0.49	0.08	5.74	0.00	0.32	0.65
INT → USE	-0.03	0.10	-0.31	0.72	-0.24	0.16
TEC → USE	0.32	0.08	4.08	0.00	0.18	0.48
EXT → ENV → USE (indirect)	0.18	0.07	2.43	0.01	0.04	0.32

Source: Summary of survey results by research team

The structural model results confirm that most hypothesized relationships are significant. External pressure strongly predicts environmental awareness (EXT → ENV: $\beta = 0.59$, $p < 0.001$), and environmental awareness in turn promotes green logistics adoption (ENV → USE: $\beta = 0.30$, $p = 0.01$). Both external pressure (EXT → USE: $\beta = 0.38$, $p < 0.01$) and cost-effectiveness perception (ECO → USE: $\beta = 0.49$, $p < 0.001$) show significant positive effects. Technological infrastructure also contributes meaningfully (TEC → USE: $\beta = 0.32$, $p < 0.001$). By contrast, internal capability does not exert a significant effect (INT → USE: $\beta = -0.03$, $p = 0.72$). In addition, the indirect effect (EXT → ENV → USE) is significant ($\beta = 0.18$, $p = 0.01$), confirming a mediation pathway. Overall, the findings highlight the joint importance of awareness, external pressure, cost–benefit considerations, and technology, while revealing that internal capabilities remain underdeveloped as a driver in this context.

4.5. Interpretation and discussion

The results of this study offer important insights into the determinants of green logistics adoption among manufacturing enterprises in Thai Nguyen province, a rapidly industrializing region in Vietnam. The analysis confirms that environmental–social awareness (ENV), external pressures (EXT), cost-effectiveness perception (ECO), and technological infrastructure (TEC) exert significant positive influences on adoption. By contrast, internal capabilities (INT) do not play a significant role, suggesting that many enterprises lack sufficient organizational resources to independently drive adoption. In addition, the findings highlight a mediation pathway: external pressures influence adoption indirectly through ENV, showing that institutional and market forces become more effective when firms internalize environmental and social concerns.

This pattern contrasts with evidence from developed economies such as Europe and East Asia, where strong regulatory frameworks and strict compliance requirements make external pressure the most powerful predictor of green logistics adoption (e.g., Liu et al., 2022). In those contexts, firms adopt green practices primarily to meet customer, legal, or competitive demands. In emerging economies, however, prior research in India and Indonesia has shown that weaker enforcement and greater cost sensitivity place more emphasis on organizational awareness, readiness, and technological

capacity (Yadav et al., 2020; Mishra et al., 2021). The results of this study are consistent with that view, underscoring the transitional nature of Vietnam's institutional environment, where external drivers first need to shape awareness before translating into actual adoption behavior.

From a theoretical perspective, this study contributes in several ways. First, it extends the application of the TPB and TOE frameworks to a provincial context in an emerging economy, showing that their explanatory power remains valid but with different weightings compared to developed economies. Second, it empirically validates the mediating role of environmental–social awareness, a mechanism often discussed but rarely tested in the green logistics literature. By positioning ENV as a pivotal bridge between external forces and adoption outcomes, the study provides a more nuanced understanding of how behavioral and contextual factors jointly shape sustainability-related decisions.

From a practical standpoint, the findings suggest that policymakers and managers should not rely solely on external regulations or customer demands to stimulate adoption. Instead, interventions should prioritize raising awareness of long-term environmental and social benefits, strengthening managerial and employee capabilities, and investing in enabling technologies such as digital platforms, automation, and smart logistics systems. Combining these internal enablers with supportive policy instruments is likely to increase the probability of adoption, even in cost-sensitive environments. Furthermore, sharing local success stories of pioneering firms could amplify the influence of external expectations and translate them into concrete organizational changes.

In summary, while external pressures remain important, their impact in emerging contexts like Thai Nguyen is mediated by firms' awareness and readiness. This finding highlights the need to tailor policy and managerial interventions to the institutional and economic realities of developing regions, thereby refining theoretical understanding and providing practical guidance for accelerating the transition toward sustainable logistics.

5. CONCLUSION

This study examined the determinants of green logistics adoption among manufacturing enterprises in Thai Nguyen province, Vietnam, by integrating the Theory of Planned Behavior (TPB) and the Technology–Organization–Environment (TOE) framework. Using PLS-SEM analysis of survey data (n = 60), the results demonstrate that environmental–social awareness (ENV), external pressure (EXT), cost-effectiveness perception (ECO), and technological infrastructure (TEC) significantly influence adoption decisions, while internal capabilities (INT) do not show a direct effect. Moreover, the findings confirm the mediating role of ENV, indicating that external drivers become effective primarily when firms internalize environmental and social concerns.

Theoretically, the study extends the application of TPB and TOE to a provincial context in an emerging economy, showing that their explanatory power remains valid but with different emphases compared to developed countries. Importantly, the validation of ENV as a mediator enriches the literature on green logistics adoption by clarifying how institutional and organizational factors jointly shape sustainability-related decisions.

Practically, the results suggest that policymakers and managers should focus on raising environmental awareness, investing in enabling technologies, and reducing cost barriers. Regulatory pressure and customer demands are not sufficient on their own; they need to be supported by communication strategies and capacity-building programs that enhance firms' perceptions of long-term benefits. Promoting successful local cases may further stimulate adoption by translating external expectations into organizational change.

This study has some limitations. First, the sample size is relatively small, with 60 valid responses from 30 enterprises. Although this is acceptable for exploratory research and PLS-SEM analysis, it may limit the generalizability of the findings. Future studies could expand the sample size and include more diverse industries and regions to enhance external validity. Second, the study is context-specific, focusing on enterprises in Thai Nguyen province. While this provides valuable localized insights, future research should consider broader geographical coverage to allow for comparative analysis.

6. ACKNOWLEDGMENTS

The authors gratefully acknowledge the contribution of Thai Nguyen University. This study belongs to the university-level science and technology project 2025, code DH2025-TN01-02.

7. REFERENCES

Ajzen. I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes. 50*(2). 179–211. https://doi.org/10.1016/0749-5978(91)90020-T

Bag. S.. Wood. L. C.. Xu. L.. & Dhamija. P. (2021). Big data analytics as an operational excellence approach to enhance sustainable supply chain performance. *Resources. Conservation and Recycling. 167*. 105421. https://doi.org/10.1016/j.resconrec.2020.105421

Chen. Y.. Li. S.. & Zhang. Q. (2023). Digital technologies and green logistics adoption: Evidence from Chinese manufacturing SMEs. *Journal of Cleaner Production. 406*. 136984. https://doi.org/10.1016/j.jclepro.2023.136984

Dubey. R.. Gunasekaran. A.. Childe. S. J.. Papadopoulos. T.. Luo. Z.. & Roubaud. D. (2022). Examining sustainable supply chain management: Insights from the technology–organization–environment framework. *Technological Forecasting and Social Change. 176*. 121452. https://doi.org/10.1016/j.techfore.2021.121452

Fornell. C.. & Larcker. D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research. 18*(1). 39–50. https://doi.org/10.1177/002224378101800104

García-Arca. J.. Prado-Prado. J. C.. & González-Portela Garrido. A. (2023). Green logistics practices in SMEs: The role of external pressures and internal drivers. *Sustainability. 15*(5). 4217. https://doi.org/10.3390/su15054217

González-Torre. P.. Lozano. S.. Adenso-Díaz. B.. & Artiba. H. (2021). Environmental and social benefits of green logistics in supply chains: A review. *International Journal of Production Research. 59*(7). 2149–2164. https://doi.org/10.1080/00207543.2020.1743894

Hair. J. F.. Hult. G. T. M.. Ringle. C. M.. Sarstedt. M.. Danks. N. P.. & Ray. S. (2022). *Partial least squares structural equation modeling (PLS-SEM) using R: A workbook*. Springer. https://doi.org/10.1007/978-3-031-06513-1

He. W.. Wang. X.. & Zhang. Y. (2024). Regulatory frameworks and the effectiveness of green logistics policies in emerging economies. *Transportation Research Part E: Logistics and Transportation Review. 182*. 103504. https://doi.org/10.1016/j.tre.2024.103504

Kamble. S. S.. Gunasekaran. A.. & Gawankar. S. A. (2023). Industry 4.0 and circular economy practices: A systematic review and research agenda. *Journal of Cleaner Production. 387*. 135878. https://doi.org/10.1016/j.jclepro.2022.135878

Kaur. H.. Singh. R. K.. & Majumdar. A. (2023). Adoption of sustainable supply chain practices in manufacturing industries: A PLS-SEM approach. *Resources. Conservation and Recycling. 195*. 106874. https://doi.org/10.1016/j.resconrec.2023.106874

Kobashi. Y.. Kameyama. Y.. & Fujii. H. (2021). External pressures and corporate environmental practices: Evidence from Japanese manufacturing firms. *Journal of Cleaner Production. 303*. 127024. https://doi.org/10.1016/j.jclepro.2021.127024

Kock. N. (2015). Common method bias in PLS-SEM: A full collinearity assessment approach. *International Journal of e-Collaboration. 11*(4). 1–10. https://doi.org/10.4018/ijec.2015100101

Liu. Y.. Zhu. Q.. & Seuring. S. (2022). Regulatory pressure. stakeholder influence and green logistics adoption: Evidence from Chinese manufacturing firms. Transportation Research Part E: Logistics and Transportation Review. 160. 102699. https://doi.org/10.1016/j.tre.2022.102699

Mishra. D.. Gunasekaran. A.. Papadopoulos. T.. & Dubey. R. (2021). Green supply chain practices in emerging economies: Empirical evidence from India. *International Journal of Production Economics. 234*. 108041. https://doi.org/10.1016/j.ijpe.2021.108041

Nguyen. T. H.. Pham. M. T.. & Le. D. A. (2024). Drivers and barriers of green logistics in Vietnam: Empirical insights from the electronics sector. *Sustainability. 16*(2). 912. https://doi.org/10.3390/su16020912

Pan. S.. Ballot. E.. & Fontane. F. (2019). The reduction of greenhouse gas emissions from freight transport by pooling supply chains. International Journal of Production Economics. 211. 160–173. https://doi.org/10.1016/j.ijpe.2019.01.011

Sharma. M.. Garg. D.. & Mangla. S. K. (2023). Industry 4.0. digitalization and sustainability: Implications for green logistics in emerging economies. *Journal of Cleaner Production. 403*. 136782. https://doi.org/10.1016/j.jclepro.2023.136782

Tornatzky. L. G.. & Fleischer. M. (1990). *The processes of technological innovation*. Lexington Books.

Yadav. G.. Luthra. S.. Jakhar. S. K.. Mangla. S. K.. & Rai. D. P. (2020). A framework to overcome sustainable supply chain challenges through solution measures of Industry 4.0 and circular economy: An automotive case. *Journal of Cleaner Production. 254*. 120112. https://doi.org/10.1016/j.jclepro.2020.120112

Zhou. J.. Liu. H.. & Ma. X. (2024). Stakeholder influence. environmental awareness. and green logistics performance: Evidence from ASEAN countries. *International Journal of Logistics Management. 35*(1). 45–68. https://doi.org/10.1108/IJLM-05-2023-0256

Zhu. Q.. & Sarkis. J. (2004). Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises. *Journal of Operations Management. 22*(3). 265–289.https://doi.org/10.1016/j.jom.2004.01.005