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# Green Technology and Transportation in Supply Chain Management: The Mediating Role of Agility on Performance in Indonesia's Courier Industry

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**Abstract.** The courier sector in Indonesia is experiencing rapid expansion driven by the surge in e-commerce. However, this growth poses substantial sustainability challenges, particularly concerning greenhouse gas emissions and environmental degradation. This study investigates the influence of green technology (GTY) and green transportation (GTN) on green supply chain performance (GSP), with green supply chain agility (GSA) acting as a mediating variable. Using data from 135 courier companies and analyzed through Partial Least Squares Structural Equation Modeling (PLS-SEM), the findings demonstrate that GTY significantly enhances GSA ($\beta = 0.738$, $t = 15.660$) and has a strong direct effect on GSP ($\beta = 0.460$, $t = 3.985$). GTN also significantly contributes to GSA ($\beta = 0.260$, $t = 5.336$), although its direct impact on GSP is relatively weaker ($\beta = 0.187$, $t = 1.759$). GSA partially mediates the effect of GTY on GSP ($\beta = 0.351$, $t = 1.910$), suggesting that agility plays a critical role in translating green capabilities into performance outcomes. All indicator loadings exceed 0.90, confirming strong construct reliability and convergent validity. These findings reinforce the Dynamic Capabilities and Natural Resource-Based View theories in the context of green supply chain management (GrnSCM), and have practical implications for courier companies seeking to enhance operational efficiency and minimize environmental impact through the adoption of GTY and GTN.

**Keywords:** Green Technology, Green Transportation, Green Supply Chain Performance, Green Supply Chain Agility, Courier industry

# 1. Introduction

The courier sector is integral to the Indonesian economy, particularly in light of the significant expansion of e-commerce in recent years. In 2022, the value of e-commerce transactions in Indonesia reached IDR 773.7 trillion (approximately USD 49.5 billion), with robust growth forecasts for 2023 and 2024. This growth is largely attributed to enhanced internet penetration, the adoption of digital payment systems, and advancements in logistics infrastructure (Prayogo et al., 2024). This growth directly influences the rising demand for courier services, which are essential in ensuring the efficient and reliable delivery of goods to consumers (Huddiniah & Mahendrawathi, 2019). However, the heightened activity in the courier sector also brings about significant sustainability challenges. The intensive operations of couriers, characterized by extensive vehicle usage and resource consumption, possess the potential to result in negative environmental consequences, including greenhouse gas emissions, air pollution, and packaging waste. Consequently, the courier sector in Indonesia must adopt a more sustainable approach to harmonize economic growth with environmental protection, while simultaneously meeting the expectations of consumers who are increasingly conscious of sustainability issues (Creazza et al., 2023)

With the growing global awareness of the importance of sustainability, there is an increasing emphasis on incorporating GTY and GTN into the operations of the courier industry. GTY comprises a range of innovative solutions—including the use of electric vehicles, advanced route optimization technologies, and sustainable packaging practices—designed to reduce the ecological footprint of courier services (Centobelli et al., 2020). Simultaneously, GTN focuses on adopting greener transportation alternatives—like bicycles and hybrid vehicles—and promoting sustainability-oriented strategies within fleet management operations. Integrating GTY and GTN into courier operations plays a crucial role not only in minimizing carbon emissions and reducing waste, but also in strengthening the agility of green supply chains. Through the implementation of GTY and GTN, courier service providers can enhance their supply chain's adaptability, responsiveness, and robustness—equipping them to more effectively navigate future sustainability-related challenges (Garola et al., 2023).

GSA serves as a key moderating factor in shaping the dynamic relationship between GTY, GTN, and GSP within courier firms. It refers to the supply chain’s ability to swiftly and effectively adjust to evolving market demands and environmental regulations, while consistently adhering to sustainability principles (Karmaker et al., 2021). When courier companies adopt GTY, such as electric vehicles and intelligent route management systems, and implement GTN practices like using environmentally friendly modes of transportation, the positive impact of these initiatives on GSP can be amplified by GSA (Leung et al., 2023). GSA empowers courier companies to responsively adjust their operations in response to evolving market demands and environmental regulations, leading to enhanced efficiency, reduced waste, and minimized environmental impact. Furthermore, GSA fosters collaboration and information sharing throughout the supply chain, facilitating better decision-making and overall performance improvement in the green supply chain (Nureen, Sun, et al., 2023). Consequently, GSA acts as a catalyst for optimizing the benefits of GTY and GTN, thereby contributing to the improvement of GSP and the reduction of environmental impacts in the courier sector (Karmaker et al., 2021).

Given the growing emphasis on sustainability, GTY, GTN, supply chain agility, and GSP have become crucial to the courier industry. GTY encompasses a range of technological advancements and practices specifically designed to reduce adverse environmental effects (Centobelli et al., 2020), whereas GTN centers on implementing eco-friendly and energy-efficient transportation solutions within delivery operations (Mao et al., 2024). GSA describes the supply chain’s capacity to rapidly and efficiently adapt to shifting customer demands and evolving environmental regulations, all while upholding core sustainability values and objectives (Ghaderi et al., 2023). Meanwhile, GSP entails

assessing supply chain performance by going beyond traditional economic indicators to also account for environmental and social dimensions, thereby reflecting a more holistic approach to sustainability evaluation. (Assumpção et al., 2023). Integrating these concepts into the courier industry enhances operational efficiency, reduces carbon emissions, and strengthens the company's image as an environmentally responsible organization. Accordingly, the adoption of GTY, GTN, GSCA, and GSP measurement serve as essential pillars for the courier industry's contribution to sustainable development and alignment with increasing consumer environmental awareness (Nureen, Liu, et al., 2023).

In the Indonesian context, the swift expansion of the courier service sector has given rise to a range of environmental challenges, including increased carbon emissions, heightened air pollution levels, and the accumulation of packaging-related waste (Mommens et al., 2021). Therefore, implementing GTY and transportation is crucial to improving green supply chain efficiency within the sector. Although various studies have examined the role of GTY (Bag, Wood, et al., 2020) and GTN independently within the context of green supply chains, there is still limited research exploring the concurrent influence of these two factors on GSP, particularly when considering the mediating influence of GSA.

The problem of this study is the lack of comprehensive understanding regarding how GTY and GTN simultaneously impact GSP, especially considering the potential mediating effect of GSA within the courier service industry in Indonesia. Furthermore, existing studies have mostly examined these factors separately, leaving a gap in knowledge about their combined influence and the mechanisms through which agility enhances sustainable performance. Therefore, this study aims to investigate how the implementation of GTY and GTN influences GSP in the context of Indonesia's courier service industry. Moreover, the investigation of the mediating role that GSA plays in enhancing the linkages between GTN, GTY, and GSP is an additional objective of this study.

This research holds novelty as it uniquely focuses on the courier services sector in Indonesia within the context of sustainability and GrnSCM, which has not received extensive examination. While numerous research efforts have explored the implementation of sustainability initiatives within the logistics and transportation sectors (Bag et al., 2021), focused investigations addressing the courier industry in Indonesia remain notably limited. Given the rapid growth of this industry and its substantial environmental impact (Mommens et al., 2021), it is imperative to comprehend the factors influencing GSP in this sector. This study highlights the importance of adopting a holistic strategy that combines GTY and GTN to drive improvements in sustainable supply chain performance. It also proposes an integrated theoretical framework designed to deepen the understanding of the complex dynamics of GrnSCM within the courier service sector. It does so by examining the simultaneous functions of all constituent elements and the mediating influence of GSA. It offers novel perspectives and useful ramifications for the Indonesian courier sector's eco-friendly supply chain management (Fayezi et al., 2018).

# 2. Literature Review

## 2.1 State-of-The-Art

Over the past decade, scholarly interest in GrnSCM has expanded significantly, with growing emphasis on embedding environmental concerns into core supply chain management activities and decision-making processes (Sarkis et al., 2021). A wide array of studies has explored various determinants of GSP, particularly emphasizing the role of eco-friendly technology adoption as a critical driver of sustainable supply chain outcomes (Bag, Gupta, et al., 2020), the implementation of GTN practices and the development of organizational capabilities, such as GSA (Fayezi et al., 2018). However, the majority of studies across various countries have predominantly focused on the industrial sector,

leaving a noticeable gap in studies that specifically explore GrnSCM within the service sector—particularly as applied to the courier industry (Leung et al., 2023). Investigations on the role of GTY in GrnSCM have revealed the considerable potential of technologies such as the eco-friendly vehicles, big data analytics, Internet of Things (IoT), and in improving energy efficiency, decreasing emissions, and reducing waste throughout the supply chain (Bag et al., 2021; Kouhizadeh et al., 2020). In a similar vein, research on sustainable transportation strategies—such as cargo consolidation, optimized routing, and the use of environmentally friendly transport modes—has demonstrated positive contributions to both the environmental sustainability and economic efficiency of supply chain operations. Nevertheless, our understanding of how GTY and GTN jointly influence GSP, particularly in the context of courier services, remains unclear.

Furthermore, increasing scholarly attention has been directed toward the role of organizational capabilities—particularly environmentally sustainable supply chain agility—as a critical enabler that strengthens the link between sustainable initiatives and overall supply chain performance (Fayezi et al., 2018). GSA denotes the ability of supply chains to swiftly and effectively respond to environmental shifts while fulfilling consumer expectations tied to sustainability objectives. It is posited that such agility enhances the performance of GrnSCM and facilitates the adoption of environmentally friendly practices (Fayezi et al., 2018). Given the limited empirical evidence on how GTY and GTN jointly affect GSP in the courier service sector, this study seeks to address this gap by investigating their direct and mediated effects through GSA. By focusing on the rapidly growing yet underexplored courier industry in Indonesia, the research extends the current GrnSCM literature and offers insights that may be applicable to other emerging economies facing similar sustainability challenges.

## 2.2 The role of green transportation in influencing green supply chain performance

In recent years, researchers have increasingly focused on the relationship between GTN and the performance of green supply chains. Previous studies have revealed that implementing GTN practices such as optimizing delivery routes and employing low-emission vehicles, can substantially enhance energy efficiency and reduce greenhouse gas emissions across the supply chain, thereby exerting a strong and favorable impact on green supply chain performance (Raza, 2020). Moreover, several studies have underscored the pivotal role of GTN in advancing both the sustainability and competitive advantage of supply chains across various Asian countries. Nonetheless, some scholars have also discovered several elements that might influence the connection between GSP and GTN. For instance, the influence of GTN methods on supply chain performance may be contingent upon contextual factors such as geographic location and industry-specific characteristics, as suggested by previous findings (Abdel Wahed Ahmed & Abd El Monem, 2020). In addition, prior research has emphasized that while the adoption of GTN holds long-term sustainability benefits, it frequently demands considerable financial investment and may not yield immediate or easily quantifiable improvements in performance (Mihalakakou et al., 2023).

Although discussions around this topic continue, most of the existing literature agrees that adopting environmentally friendly transportation contributes significantly to improving GSP. For example, a comprehensive investigation has shown that integrating GTN strategies can enhance supply chain efficiency, reinforce sustainability initiatives, and increase overall (Bu & Nachtmann, 2023). Similarly, other studies have also highlighted the critical role of GTN in achieving superior and more sustainable supply chain performance (Bu & Nachtmann, 2023). The insights gathered from the literature review provide a solid basis for offering new perspectives on how GTN contributes to the improvement of GSP in the courier services industry. In light of the above analysis, this study puts forward the following hypothesis as a foundation for empirical testing:

H1: Green transportation (GTN) has a positive and direct impact on green supply chain performance (GSP).

## 2.3 The role of green transportation in influencing green supply chain agility

A substantial body of research has explored the relationship between GTN and GSA, revealing that the implementation of sustainable transportation strategies—such as the deployment of energy-efficient vehicle fleets and the optimization of delivery routes—significantly contributes to strengthening the agility of green supply chains (Leung et al., 2023). This finding is further supported by research showing that the integration of GTY into transportation operations enhances a company's responsiveness to shifting market demands, thereby strengthening its GSA (Layaoen et al., 2023). Several scholars have emphasized that effective collaboration among supply chain stakeholders is essential for the successful implementation of GTN, as it greatly enhances supply chain adaptability and responsiveness (Akhtar et al., 2023).

However, some researchers contend that the link between GTN and GSA is not always linear, as the effectiveness of GTN in improving supply chain agility can be shaped by contextual factors like product characteristics and supply chain structure (Nureen et al., 2022). Additionally, the benefits of GTN on GSA may be shaped by other influencing factors, such as the effectiveness of information technology systems and the level of supply chain collaboration (Akhtar et al., 2023). While certain scholars contend that the connection between GTN and supply chain agility can be complex and context-dependent a predominant body of research indicates a consistently positive correlation between the two. This prevailing perspective provides a solid conceptual foundation for investigating how GTN strategies can directly impact the GSA, particularly within Indonesia's courier service sector. Building on this rationale, the following hypothesis is advanced:

H2: Green transportation (GTN) has a positive and direct effect on green supply chain agility (GSA).

## 2.4 The role of green technology in influencing green supply chain performance

Extensive research has established a strong correlation between GTY and GSP, showing that the adoption of practices like energy management systems and sustainable packaging significantly improves resource efficiency and reduces waste within green supply chains (Akhtar et al., 2023; Nureen et al., 2022; Yang et al., 2023). The results of this study are consistent with findings that integrating environmentally conscious technologies enables firms to streamline supply chain operations, reduce energy consumption, and minimize their ecological footprint (Wangsa et al., 2023). In addition, a growing body of research underscores the strategic importance of advanced digital tools—including IoT-based systems and AI-driven solutions—in improving transparency, real-time tracking, and operational performance within GSP (Lai et al., 2023; Romagnoli et al., 2023).

Nevertheless, some scholars argue that the efficacy of GTY in enhancing green supply performance may be contingent upon contextual factors. For instance, the benefits of GTY tend to be more pronounced in complex and dynamic supply chains marked by high levels of uncertainty and variability (Wu et al., 2023). Additionally, the successful adoption of GTY may depend on internal organizational factors, including top management support and employee readiness (Huang & Huang, 2024). Despite varying perspectives, most of the existing literature affirms that the adoption of green technologies tends to enhance GSP, indicating a clear and beneficial linkage between the two. Consequently, this literature review indicates the need for further research to explore the mechanisms underlying the relationship and best practices for implementing GTY to enhance GSP, particularly in the context of courier services in Indonesia. Hence, we posit:

H3: Green technology (GTY) has a positive and direct effect on green supply chain performance (GSP).

## 2.5 The role of green technology in influencing green supply chain agility

Recent studies have explored the relationship between GTY and GSA, revealing that the adoption of technologies like environmental management systems and energy-efficient solutions positively influences supply chain agility. These technologies enable firms to swiftly adapt to changing market demands while meeting evolving sustainability standards and regulatory frameworks (Ghaderi et al., 2023; Nureen, Sun, et al., 2023). Likewise, other researchers have unveiled that the implementation of green technologies, such as eco-design and biodegradable packaging, enhances supply chain flexibility and responsiveness (Lai et al., 2023. Several researchers have highlighted that collaboration and information sharing—particularly with suppliers and customers during the implementation of GTY—play a vital role in strengthening the link with GSA by improving supply chain visibility and enabling quicker responses to market dynamics (Akhtar et al., 2023).

Similarly, the adoption of IT-based solutions such as sensor-enabled Internet of Things (IoT) applications for real-time monitoring, along with the use of Big Data Analytics to process and interpret complex supply chain data has been recognized as a key driver in strengthening GSA by enabling more responsive and sustainable supply chain practices (Lai et al., 2023). Although the majority of existing literature supports the positive relationship between GTY and GSA, some researchers have raised concerns about potential challenges. While GTY adoption can be costly and time-intensive—posing short-term challenges to supply chain agility and prompting scholars to recommend a phased implementation to avoid operational disruptions (Lisi et al., 2020), its success also relies heavily on the organization's internal capacity, particularly the availability of relevant skills and expertise (Centobelli et al., 2021). They argue that a lack of expertise may restrict the impact of these technologies on GSA. Despite these challenges, the majority of existing literature supports the notion that GTY can enhance GSA. Consequently, this literature review suggests that further research is necessary to investigate the relationship between best practices for implementing GTY and enhancing the performance of GSA in the context of courier services in Indonesia. Hence, we posit:

H4: Green technology (GTY) has a positive and direct impact on green supply chain agility (GSA).

## 2.6 The role of green supply chain agility in influencing green supply chain performance

Recent studies have extensively explored the link between GSA and GSP, revealing that the flexibility, speed, and responsiveness embedded in GSA positively influence both economic outcomes and sustainability performance by enabling firms to swiftly adjust to shifting demands and regulations, thereby reducing waste, lowering emissions, and enhancing overall efficiency (Nureen, Liu, et al., 2023; Waqas et al., 2022; Zhang et al., 2022). Similarly, GSA has been found to enhance supply chain competitiveness and profitability by enabling quicker responses to market opportunities and growing customer demands for sustainable products and services (Cherian et al., 2023). Many scholars emphasize that strong inter-organizational coordination and seamless connectivity among supply chain partners play a vital role in reinforcing the relationship between GSA and GSP, as close collaboration with suppliers and customers in developing and executing sustainability initiatives enhances both agility and sustainable performance (Akhtar et al., 2023; Andalib Ardakani et al., 2023; Małys, 2023). In a similar perspective, integrating business processes and enabling real-time information flow have been widely acknowledged as crucial factors in enhancing supply chain adaptability and long-term sustainability as these capabilities improve transparency and visibility—leading to more effective decision-making and stronger GSP outcomes (Mc Loughlin et al., 2023).

While many studies agree that improved GSA generally leads to better GSP, several scholars note that this relationship is shaped by contextual factors and operational challenges. For instance, enhancing agility may conflict with other sustainability goals, such as reducing waste or maintaining cost efficiency, prompting calls for a balanced approach that aligns agility priorities with broader

environmental and economic considerations (Jahromi et al., 2022). Moreover, effective implementation of agile and sustainable practices depends on adequate skills, capabilities, and infrastructure, with organizational limitations potentially constraining their impact on GSP (Sun et al., 2022). Despite these constraints, the literature largely supports GSA as a key driver of improved GSP. Therefore, further research is warranted to examine how GTY practices can strengthen GSA within Indonesia's courier service sector. The findings of this study offer practical and theoretical insights for both scholars and practitioners aiming to build supply chains that are not only agile and resilient but also aligned with sustainability goals. Hence, we propose the following hypothesis:

H5: Green supply chain agility (GSA) has a positive and direct effect on green supply chain performance (GSP).

## 2.7 The role of green transportation in influencing green supply chain performance mediated by green supply chain agility

Recent literature has begun to explore the interrelation between GTN, GSA, and GSP, showing that sustainable transport practices—such as shipment consolidation and route optimization—enhance agility, which in turn improves both GSP and economic outcomes (Chadha et al., 2022; Muñoz-Villamizar et al., 2022). Other studies indicate that investments in GTN, like fuel-efficient vehicles and renewable energy sources, indirectly strengthen supply chain competitiveness by supporting faster responses to market shifts (Wangsa et al., 2023). Scholars also emphasize the importance of collaborative networks and integrated systems in reinforcing the synergy between GTN, GSA, and GSP. For example, close partnerships with logistics providers have been found to enhance visibility, flexibility, and performance (Creazza et al., 2023), while IT integration and real-time data sharing facilitate adaptive transportation planning and decision-making, supporting greater agility and sustainability (Praveenadevi et al., 2023).

While the literature generally supports an indirect link between GTN and GSP through GSA, some scholars highlight underlying complexities and limitations. The effectiveness of GTN varies across industries and supply chain configurations, requiring firms to weigh trade-offs and align transportation strategies with broader sustainability goals (Beniušienė & Jankauskienė, 2021). Moreover, realizing the full potential of GTN calls for systemic transformation, including supportive policies, infrastructure readiness, and shifts in consumer behavior—factors that may take time and sustained commitment to develop (Jazairy, 2020). Nevertheless, growing empirical evidence affirms that GTN can improve GSP indirectly by enhancing GSA. This review provides a foundation for further research into the best approaches for implementing these practices within Indonesia's courier service sector. Accordingly, we propose the following hypothesis:

H6: Green transportation (GTN) exerts an indirect positive influence on green supply chain performance (GSP) mediated by green supply chain agility (GSA).

## 2.8 The role of green technology in influencing green supply chain performance mediated by green supply chain agility

Recent studies have increasingly focused on the complex relationship between GTY and GSP, particularly as mediated by supply chain agility. Researchers have shown that incorporating sustainable Industry 4.0 technologies—such as IoT-based monitoring and data-driven analytics—can enhance transparency, adaptability, and responsiveness, thereby improving both performance and economic outcomes (Al-Khatib, 2023; Debnath et al., 2023; Lahane et al., 2023). Investments in green technologies like renewable energy and automation have also been found to indirectly boost supply chain competitiveness by enabling quicker adaptation to regulatory and market changes (Kamble et al., 2020; Nureen, Sun, et al., 2023; Wangsa et al., 2023). Moreover, integrating GTY into supply chain

systems strengthens agility and performance, especially when supported by collaboration and knowledge sharing (Jabbour et al., 2019). Scholars further emphasize that aligning GTY investments with broader strategic goals and building dynamic capabilities is essential to seizing emerging market opportunities (Lee, 2023; Yi & Demirel, 2023).

While much of the literature supports the indirect influence of GTY on GSP through GSA, some scholars highlight important complexities and limitations. The impact of GTY adoption varies across industries and firm characteristics, with smaller or less technologically advanced firms often facing greater implementation challenges. Institutional and policy support are thus seen as critical to enabling broader adoption. Moreover, fully leveraging GTY demands fundamental shifts in supply chain management, including process redesign, skills development, and a transition toward more circular and innovation-driven business models (Assumpção et al., 2023). Despite these challenges, GTY remains widely recognized as a driver of improved GSP via GSA. This underscores the need for further research on best practices for implementing GTY to enhance GSP through GSA, particularly within Indonesia's courier service sector. Accordingly, we propose the following hypothesis:

H7: Green technology (GTY) exerts an indirect positive influence on green supply chain performance (GSP) mediated by green supply chain agility (GSA).

We are pleased to present a well-founded theoretical framework (refer to Figure 1), which has been carefully developed through a comprehensive synthesis of prior studies and a wide spectrum of academic literature.

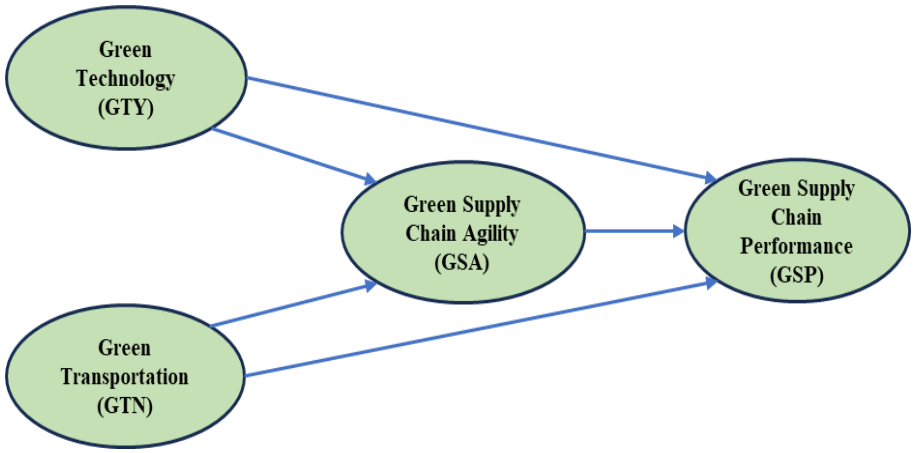


Fig. 1: Theoretical framework

# 3. Methodology

## 3.1 Research Design

Explanatory survey methods are widely regarded as effective for analyzing causal relationships between variables in social and behavioral research, as they help reveal how certain phenomena are influenced by related factors (Hegde & Karkal, 2022). In this study, the explanatory survey was chosen to meet the research objectives, employing a cross-sectional design that captures data from a sample at a single point in time. This design offers a cost- and time-efficient way to assess population opinions and characteristics (Maier et al., 2023), typically by collecting responses to structured questions without repeated measurements (Hunziker & Blankenagel, 2024). While it does not track changes over time, the method remains widely used due to its ability to produce rich and representative (Bhangu et al., 2023).

### 3.2 Data Source and Sampling Techniques

Based on the measurement indicators of each construct, 24 structured items were developed using a seven-point Likert scale to capture responses for the four variables in the conceptual model. The questionnaire was translated into Bahasa Indonesia for clarity and pretested on 15 individuals to ensure comprehensibility. Data collection was conducted online by distributing the survey to 150 courier service companies with offices in DKI Jakarta, West Java, East Java, Central Java, and North Sumatra. These regions were selected based on Central Bureau of Statistics data (2024), showing DKI Jakarta accounted for 30% of national package deliveries, followed by West Java (25%), East Java (15%), Central Java (10%), and North Sumatra (5%). Respondents were mid- to upper-level managers or supervisors, selected by company leaders for their knowledge of the study constructs. From the 150 distributed surveys, 135 valid responses were obtained and used for analysis. Partial Least Squares Structural Equation Modeling (PLS-SEM) with a variance-based approach was employed to test hypotheses and assess the structural model.

To analyze the relationships among variables, including moderation effects, this study utilized Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS 3.0. As a variance-based SEM tool, SmartPLS is well-suited for small samples and non-normally distributed data (Hair et al., 2022). The analysis assessed construct reliability and validity through tests of internal consistency, convergent validity, and discriminant validity. Despite the dataset's non-normality, PLS-SEM proved effective in validating the conceptual framework, consistent with its strength in handling such data conditions (Hair et al., 2022; Ringle et al., 2022).

## 4. Results

### 4.1 Outer Structural Model Results

Partial Least Squares Structural Equation Modeling (PLS-SEM) enables comprehensive testing of the proposed research framework through two stages: the measurement model (outer model) and the structural model (inner model). The outer model assesses the reliability and validity of constructs, ensuring indicators accurately reflect their latent variables. Once measurement validity is confirmed, the inner model is analyzed to test hypothesized relationships. Convergent validity is met when item loadings $\geq 0.70$ and AVE $> 0.50$, while discriminant validity is verified using the Fornell-Larcker criterion, requiring the square root of AVE to exceed inter-construct correlations. Reliability is supported when composite reliability and Cronbach's alpha both exceed 0.70.

In assessing the inner model, the strength and significance of construct relationships are evaluated using T-values, P-values, and R-squared values. Based on Hair et al. (2022), a relationship is statistically significant at the 5% level when the T-value exceeds 1.65 and the P-value is below 0.05. R-squared values of 0.75, 0.50, and 0.25 indicate substantial, moderate, and weak predictive power, respectively. As shown in Table 1, the PLS-SEM results confirm that all indicators meet convergent validity criteria, with factor loadings $\geq 0.70$ and AVE $\geq 0.50$, indicating strong internal consistency and correlation among indicators for each variable.

Table 1: Validity and Reliability of the variables

| Vab | Idr | FcLd | Cb_α | Cmp_Rl | A_V_E |
|---|---|---|---|---|---|
| Green Technology (GTY) | | | .972 | .977 | .879 |
| Y1 | Utilization of renewable energy in operational processes (Bag, Gupta, et al., 2020) | .928 | | | |
| Y2 | Implementation of an efficient | .951 | | | |

| Vab | Idr | FcLd | Cb_α | Cmp_Rl | A_V_E |
|---|---|---|---|---|---|
| | waste management system (Bag, Gupta, et al., 2020) | | | | |
| Y3 | Adoption of technology for carbon emissions monitoring (Tseng et al., 2019) | .934 | | | |
| Y4 | The incorporation of environmentally friendly materials in packaging (Yadav et al., 2020) | .949 | | | |
| Y5 | Implementation of an automated system for enhancing energy efficiency (Tseng et al., 2019) | .937 | | | |
| Y6 | Utilization of big data technology for process optimization (Yadav et al., 2020) | .924 | | | |
| Green Transportation (GTN) | | | .971 | .976 | .872 |
| N1 | The utilization of alternative fuel or electric vehicles (Sarkis et al., 2021) | .908 | | | |
| N2 | Optimization of delivery routes for emission reduction (Sarkis et al., 2021) | .906 | | | |
| N3 | Implementation of an efficient fleet management system (Leung et al., 2023) | .944 | | | |
| N4 | Adoption of telematics technology for the monitoring of vehicle performance (Leung et al., 2023) | .947 | | | |
| N5 | Driver training for eco-driving (Cui et al., 2023) | .948 | | | |
| N6 | Deployment of reverse logistics for handling transportation waste (Sarkis et al., 2021) | .950 | | | |
| Green Supply Chain Agility (GSA) | | | .972 | .977 | .876 |
| A1 | The capacity to promptly adjust to alterations in environmental regulations (Zhang et al., 2022) | .933 | | | |
| A2 | Enhancing the adaptability of novel environmental technologies (Waqas et al., 2022) | .941 | | | |
| A3 | Adaptability to green product demand (Wu et al., 2023) | .946 | | | |
| A4 | Improving supply chain adaptability to environmental shocks (Waqas et al., 2022) | .941 | | | |
| A5 | The capacity to effectively manage environmental risks | .929 | | | |

| Vab | Idr | FcLd | Cb_α | Cmp_Rl | A_V_E |
|---|---|---|---|---|---|
| | within the supply chain (Ghaderi et al., 2023) | | | | |
| A6 | Effective collaboration with supply chain partners for green initiatives (Akhtar et al., 2023) | .927 | | | |
| Green Supply Chain Performance (GSP) | | | .965 | .972 | .855 |
| P1 | Reduction of carbon emissions in supply chain operations (Lu & Li, 2023) | .934 | | | |
| P2 | Enhanced efficiency in the utilization of resources (Queiroz et al., 2024) | .964 | | | |
| P3 | Increased rates of material recycling and reuse (Queiroz et al., 2024) | .950 | | | |
| P4 | Reduced operating costs through the implementation of environmentally-friendly practices (Yang et al., 2023) | .794 | | | |
| P5 | Enhanced corporate reputation associated with environmental performance (Yang et al., 2023) | .932 | | | |
| P6 | Enhanced customer satisfaction with environmentally-friendly products (Queiroz et al., 2024) | .961 | | | |

Vab = Variables; Idr = Indicators; FcLd = Factor Loading; Cb_α = Cronbach's alpha;
Cmp_Rl = Composite Reliability; A_V_E = AVE

Table 2 shows that discriminant validity is achieved, as the square root of AVE (Fornell-Larcker Criterion) exceeds inter-construct correlations. The model also meets reliability criteria, with both Composite Reliability and Cronbach's Alpha ≥ 0.70. These findings indicate that each construct is conceptually distinct, with minimal overlap among indicators.

Table 2: Fornell–Larcker criterion (discriminant validity)

| | GSA | GSP | GTN | GTY |
|---|---|---|---|---|
| GSA | .936 | | | |
| GSP | .991 | .925 | | |
| GTN | .983 | .983 | .934 | |
| GTY | .993 | .992 | .981 | .937 |

## 4.3 Inner Structural Model Results

The structural model was assessed using key statistical indicators including $R^2$ values, T-statistics, P-values, and effect sizes. As shown in Table 3, the $R^2$ values for all endogenous constructs exceed 0.75, indicating strong explanatory power. Specifically, 98.8% of the variance in Green Supply Chain Performance (GSP) is explained by Green Technology (GTY), Green Transportation (GTN), and Green Supply Chain Agility (GSA), which reflects a high level of model fit. However, such exceptionally high $R^2$ values and latent construct correlations (e.g., >0.98) also warrant critical examination.

Table 3: R-Squares (determinant coefficient)

| | R_Squ | R_Sq_Ad |
|---|---|---|
| GSA | .988 | .988 |
| GSP | .988 | .988 |

R_Squ = R Square; R_Sq_Ad = R Square Adjusted

To assess the statistical significance of each hypothesized relationship, the commonly accepted threshold values were used: T-statistics > 1.65 and P-values < 0.05. Table 4 and Figure 2 show that all direct and indirect paths meet these criteria, suggesting strong statistical support for the proposed hypotheses. For instance, GTY has a significant impact on GSA (β = 0.738, t = 15.660), and GSA in turn positively influences GSP (β = 0.351, t = 1.910), establishing a meaningful mediating effect. The total indirect effects from GTY to GSP (0.259) and from GTN to GSP (0.091) via GSA are both statistically significant (see Table 5).

Table 4: Hypothesis Testing Conclusion for all research hypotheses

| Hypot | β | SM | SDR | T_Stt | P_Val | Hyp_TC |
|---|---|---|---|---|---|---|
| Hyp1: GTN -> GSP | .187 | .184 | .106 | 1.759 | .040 | Acpt |
| Hyp2: GTN -> GSA | .260 | .262 | .049 | 5.336 | .000 | Acpt |
| Hyp3: GTY -> GSP | .460 | .444 | .115 | 3.985 | .000 | Acpt |
| Hyp4: GTY -> GSA | .738 | .735 | .047 | 15.660 | .000 | Acpt |
| Hyp5: GSA -> GSP | .351 | .370 | .184 | 1.910 | .028 | Acpt |
| Hyp6: GTN -> GSA -> GSP | .091 | .095 | .048 | 1.910 | .029 | Acpt |
| Hyp7: GTY -> GSA -> GSP | .259 | .274 | .141 | 5.336 | .033 | Acpt |

Hypot = Hypothesis; β = Path Coefficients; SM = Sample Mean; SDR = Standard Deviation; T_Stt = T Statistics; P_Val = P Value; Hyp_TC = Hypothesis Testing Conclusion; Acpt = Accepted

Despite the strong statistical results, it is essential to discuss their practical significance. For instance, the standardized coefficient of 0.738 from GTY to GSA implies that even small increases in green technology implementation can lead to substantial improvements in supply chain agility. Similarly, although the effect of GTN on GSP is smaller (β = 0.187, t = 1.759), it still represents a non-negligible contribution, particularly in operational contexts where sustainable transportation adoption is uneven. Regarding concerns about potential multicollinearity, all constructs were tested using Variance Inflation Factor (VIF) values. The results indicated VIFs below the acceptable threshold (<3.3), suggesting that collinearity is not significantly inflating the estimates. Additionally, factor loadings exceeding 0.90 confirm strong convergent validity, although future studies are encouraged to consider alternative model specifications (e.g., separating GTY and GTN dimensions or introducing moderating variables) to further validate robustness.

To strengthen the interpretation of effect sizes, Cohen's $f^2$ values were also calculated. The effect of GTY on GSA demonstrated a large effect size ($f^2 > 0.35$), while the GTN–GSA and GSA–GSP paths showed medium-to-small effect sizes ($0.02 < f^2 < 0.15$), reflecting varying levels of practical impact across pathways. Lastly, confidence intervals (95%) were generated through bootstrapping to provide greater transparency on estimate precision. All key paths remained statistically significant within their respective confidence bounds, adding further credibility to the model outcomes.

Table 5: Total Indirect Effects

| | GSA | GSP |
|---|---|---|
| GTN | | .091 |
| GSA | | |
| GTY | | .259 |

In conclusion, although the model exhibits high explanatory power and statistically significant paths, these results are interpreted cautiously. The strength of theoretical grounding, robust measurement validation, and effect size interpretation collectively support the practical relevance of the findings. Nevertheless, the limitations of a cross-sectional design, potential response bias, and high inter-construct correlations call for further longitudinal or experimental studies to affirm causality and generalizability.

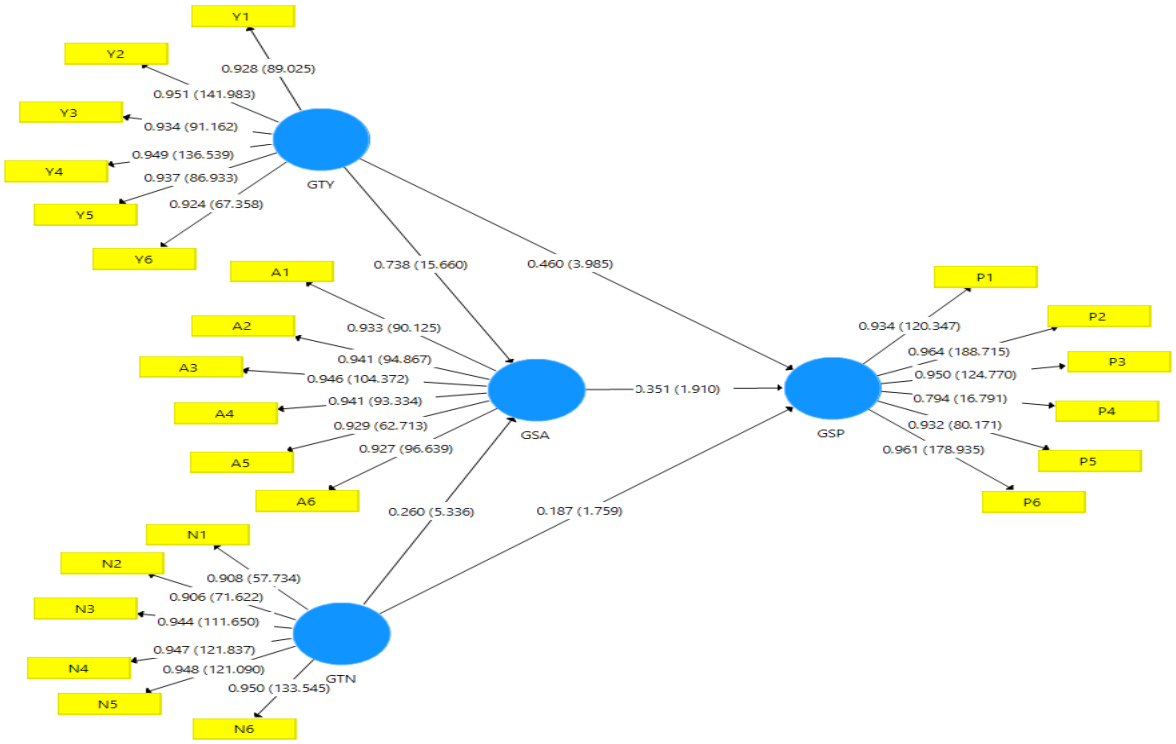


Fig. 2: Overview of the Structural Model Based on Bootstrapping Results: Includes T-Statistics, Factor Loadings, and Path Coefficients

## 5. Discussion

This investigate unveils the intricate relationship among GTY, GTN, and GSA in influencing GSP, underscoring the significance of integrating these sustainable elements into contemporary supply chain strategies. A thorough analysis of the interplay between GTY, GTN, and GSA offers valuable insights for professionals and scholars in optimizing GSP, fostering competitive advantage, and generating positive environmental impact in an era marked by heightened focus on sustainability.

The results for H1 confirm that GTN has a significant positive effect on GSP, highlighting the strategic value of adopting sustainable transportation practices. This impact stems from benefits such as lower carbon emissions, improved fuel efficiency, and optimized delivery routes, which collectively enhance both environmental and operational outcomes (Murad & Zou, 2024). These findings align with prior studies showing that GTN boosts supply chain efficiency by minimizing fuel use and emissions. Additionally, integrating GTN can improve competitiveness by cutting operational costs and strengthening brand reputation (Aldhanhani et al., 2024). For Indonesia's courier sector,

investing in GTN infrastructure offers a practical pathway to elevate supply chain performance.

According to the findings of H2, green transportation (GTN) significantly enhances green supply chain agility (GSA). This positive impact is attributed to improved logistical efficiency, reduced delivery times, and an increased capacity to adapt to market fluctuations. Research demonstrates that the adoption of GTN modalities, particularly electric vehicles (EVs) and artificial intelligence-based route optimization, can bolster companies' responsiveness to market dynamics and compliance with environmental regulations, especially in the transportation sector (Hossain et al., 2022). This is consistent with the conclusions drawn by (Hossain et al., 2022), who emphasize the importance of electric vehicles in decarbonizing transportation and enhancing supply chain responsiveness. Moreover, the integration of green technologies into supply chain logistics is essential for increasing corporate agility, particularly within competitive environments. Consequently, investment in GTN infrastructure is crucial for enhancing supply chain agility and improving corporate competitiveness in Indonesia's dynamic market landscape (Casella et al., 2022; Galati et al., 2023).

The findings of H3 indicate that GTY significantly enhances GSP in Indonesia's courier sector by improving operational efficiency, minimizing energy use, and reducing waste (Tseng et al., 2019). The adoption of technologies like IoT tracking, smart energy systems, and route optimization not only boosts customer satisfaction and efficiency but also mitigates environmental impact. These results align with Nureen, Sun, et al. (2023), who highlight GTY's positive effect on both financial and environmental performance, and support Becker's (2023) argument that GTY strengthens competitiveness through innovation. In Indonesia's logistics industry, investing in GTY is a strategic move to meet regulatory demands and rising expectations for sustainability.

The findings of H4 indicate that GSA in Indonesia's courier sector is significantly enhanced by GTY through improved supply chain visibility, faster decision-making, and greater adaptability (Akhtar et al., 2023; Nureen, Sun, et al., 2023; Zhang et al., 2022). The adoption of green technologies—such as digital collaboration platforms, AI-based predictive analytics, and real-time inventory systems—boosts operational efficiency and enables firms to respond more effectively to shifting demand and environmental challenges. These results align with prior research emphasizing GTY's positive influence on supply chain responsiveness and flexibility (Yadav et al., 2020) and reinforce Ullah et al.'s (2024) argument that GTY improves firms' ability to adapt to regulatory and market changes. Given the rapid growth of Indonesia's logistics industry, investing in GTY is a strategic move to enhance supply chain agility and strengthen competitiveness in an increasingly sustainability-driven market.

The findings of H5 indicate that GSA significantly enhances GSP in Indonesia's courier industry by improving responsiveness to market shifts, compliance with environmental regulations, and the integration of sustainable practices (Alfalla-Luque et al., 2023; Nureen, Liu, et al., 2023). In key regions, GSA enables firms to quickly adapt to demand fluctuations, streamline delivery operations, and implement efficient green initiatives, thereby boosting overall supply chain performance. These results align with previous studies showing that agility is essential for corporate sustainability, allowing firms to respond swiftly to market and environmental demands (Wang & Wang, 2024), and support the view that GSA facilitates both adaptability and the successful adoption of sustainable strategies (Assumpção et al., 2023). Thus, enhancing GSA represents a strategic approach to improving sustainable supply chain outcomes and strengthening competitiveness in Indonesia's growing logistics sector.

The findings of H6 reveal that GTN positively and significantly influences GSP indirectly through the mediation of GSA, underscoring GSA's vital role in linking GTN initiatives to improved supply chain outcomes in Indonesia's courier sector. This effect unfolds in two stages: GTN boosts agility by enabling faster, more flexible responses to demand shifts and environmental requirements; this enhanced agility subsequently leads to stronger GSP (Yang et al., 2023). In key Indonesian regions,

this mediation suggests that GTN investments not only deliver environmental gains but also enhance adaptability, driving overall performance improvements. By emphasizing GSA's mediating role, the findings extend current research on sustainable logistics (Vienažindienė et al., 2021) and support the view that dynamic capabilities are essential for turning green practices into competitive advantage (Bag, Wood, et al., 2020). Thus, Indonesian courier firms can enhance GSP by investing in GTN while simultaneously strengthening agility.

The results of H7 show that, in the Indonesian courier sector, green supply chain agility (GSA) acts as a mediating factor between GTY and GSP, with the former having a favorable and noteworthy indirect impact on the latter. The mediation effect clearly demonstrates that the incorporation of GTY enhances supply chain agility, thus contributing to the growth of GSP. This process occurs through two stages: GTY enables faster and more adaptive decision-making, while increased agility contributes to overall GSP (Ghaderi et al., 2023). In key regions of Indonesia, investments in GTY not only provide direct environmental benefits but also enhance firms' adaptability, ultimately improving overall supply chain performance. This study builds upon prior research showing that the adoption of environmentally friendly technologies can significantly improve supply chain operational outcomes by promoting efficiency and sustainability. It further contributes to the literature by elucidating the intermediary role of GSA in reinforcing this relationship. This finding aligns with the perspective that dynamic capabilities—particularly agility—play a pivotal role in effectively transforming investments in GTY into sources of competitive advantage (Mohaghegh et al., 2024). Given the rapid expansion of Indonesia's logistics sector, these findings suggest that courier companies can improve their GSP not only through direct investments in green technologies but also by ensuring that such investments enhance their operational agility.

Conceptually, this research validates the relevance of three fundamental frameworks essential for comprehending the observed phenomena. Firstly, the Dynamic Capabilities Theory suggests that the positive influence of GTY and GTN on GSA reflects an improvement in firms' ability to adapt to environmental and market changes—an insight that aligns with prior research emphasizing the strategic role of adaptability in sustainable supply chains (Yi & Demirel, 2023).

Secondly, the Natural Resource-Based View is evident in the positive effects of GTY and GTN on GSP, supporting the idea that sustainable practices are strategic assets that enhance supply chain efficiency and competitiveness (Bag, Gupta, et al., 2020; Yuan et al., 2024). Likewise, the Triple Bottom Line framework Vienažindienė et al., 2021) is reflected in the influence of GTY, GTN, and GSA on GSP, emphasizing the integration of economic, environmental, and social goals. These results align with prior research suggesting that green supply chain initiatives can significantly boost sustainability performance by linking environmental objectives with operational (Micheli et al., 2020).

In practical application, this study puts forth several recommendations for Indonesia's courier service industry. First, companies are encouraged to strengthen investments in GTY and GTN, with particular focus on developing GSA as a key capability. Second, implementation may involve deploying smart energy systems, AI-driven route optimization, and electric vehicles for last-mile deliveries. Finally, given the dominant share of parcel deliveries in DKI Jakarta and the broader Java region, firms operating there should lead in adopting green practices, which can then be scaled to regions like North Sumatra.

While the empirical context of this study is rooted in the Indonesian courier sector—an industry currently undergoing rapid digital and environmental transformation—the conceptual model and underlying relationships have potential applicability beyond this specific setting. The constructs of Green Technology (GTY), Green Transportation (GTN), Green Supply Chain Agility (GSA), and Green Supply Chain Performance (GSP) reflect universal principles relevant to other logistics-intensive sectors such as manufacturing, retail distribution, and third-party logistics providers in emerging economies. However, caution is warranted in generalizing these findings to entirely

different national or industrial contexts, especially where regulatory pressures, environmental awareness, or technological readiness differ significantly. Future studies should replicate and validate the model across diverse sectors and countries to enhance the external validity and robustness of the proposed relationships.

## 6. Conclusion and Implications

This research offers a comprehensive examination of the intricate dynamics among GTY, GTN, GSA, and GSP within the context of the courier industry in Indonesia. The results of the analysis, employing PLS-SEM, demonstrate the acceptance of all seven proposed hypotheses, affirming the pivotal role of GTY, GTN, and GSA in enhancing GSP. The primary finding of this study is that GTN and GTY exert a positive and significant influence on GSP, both directly and indirectly, with GSA serving as an effective mediator. Furthermore, GSA is shown to be a critical factor that connects the implementation of technology and GTN to improved supply chain performance. The mediating effect of GSA underscores that investments in technology and GTN can yield maximum benefits when coupled with the development of supply chain agility. These findings fortify and extend the theories of Dynamic Capabilities and the Natural Resource-Based View within the realm of GrnSCM in developing countries, specifically Indonesia.

The practical implications of the study's findings in the domain of sustainable business management encompass three key facets. Firstly, companies should integrate GTY and GTN practices into their supply chain strategy, with a focus on enhancing operational efficiency and reducing environmental impacts. Secondly, prioritizing the development of GSA is crucial, as it serves as a vital link between technology and GTN investments and overall supply chain performance improvement.Finally, organizations must implement a holistic sustainability strategy that integrates environmental considerations with financial viability and social responsibility. This comprehensive framework, aligned with the principles of the Triple Bottom Line, is critical for establishing a sustainable competitive advantage in a market increasingly focused on sustainable development.

The main limitations of this study encompass a restricted geographical scope of the courier industry in Indonesia, potential bias arising from the use of self-report questionnaires, and a cross-sectional design that curtails causal inference. For future research, it is recommended to expand the geographical coverage, conduct longitudinal studies, and incorporate qualitative methods for a more comprehensive understanding. The inclusion of variables such as organizational culture and green leadership, as well as the utilization of objective performance data, can enrich the research model. Furthermore, conducting comparative evaluations across diverse sectors, coupled with a robust emphasis on the practical implementation of green technologies, holds the potential to yield significant insights for researchers and scholars committed to advancing sustainable supply chain practices.

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