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Digital Technology in Road Freight Logistics for Global Supply Chains

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Abstract: Digital transformation plays a crucial role in improving operational efficiency and transparency of road logistics services in global supply chains. Technological innovations such as the Internet of Things (IoT), artificial intelligence (AI), and intelligent transportation systems (ITS) have revolutionized logistics processes through real-time tracking, route optimization, predictive vehicle maintenance, and more accurate inventory management. However, the adoption of these technologies is uneven between developed and developing countries due to differences in infrastructure, regulations, and human resource skills. This study aims to analyze the role of technology in improving logistics efficiency, compare adoption rates across countries, and identify barriers and solutions to achieving an inclusive and sustainable digital transformation. Thus, this research contributes to the development of literature and policy practices that support a resilient, transparent, and environmentally friendly road logistics system.

Keyword: Efficiency, Internet of Things, global supply chain, technological innovation, AI, ITS, digital transformation

INTRODUCTION

Road logistics accounts for about 80% of global goods distribution but still faces significant challenges in efficiency, transparency, and sustainability, particularly in the context of digital transformation (Ivanova, 2023; Romanova et al., 2023). In Indonesia, logistics costs reach 16% of GDP, caused by inadequate infrastructure and widespread informal practices (Tanuwidjaja, 2012). This study aims to examine the role of digital technology—such as the Internet of Things (IoT), artificial intelligence (AI), and intelligent transportation systems (ITS)—in improving efficiency and transparency of road logistics; analyze adoption gaps between developed and developing countries; and identify challenges in creating an inclusive

digital transformation (Vasiljević & Tošić, 2019; Ivanova, 2023). The approach used is descriptive qualitative with a combination of literature study and structured observation in case studies of DHL in Germany and JNE in Indonesia. Thematic analysis results show that the implementation of IoT, AI, and ITS at DHL can increase efficiency by up to 25% and transparency up to 95%, thanks to digital infrastructure support and supportive European Union policies (Romanova et al., 2023; Ivanova, 2023; Doll et al., 2017). In contrast, JNE is still limited to basic IoT use (such as GPS), which increases transparency up to 70% but only yields a 5–10% increase in efficiency due to poor road conditions and low workforce skills (Tanuwidjaja, 2012; Hassan et al., 2019). The main obstacles identified include high initial investment costs, limited digital infrastructure, and slow adoption of low-emission technology (Christova, 2024; Hassan et al., 2019). This study recommends strategic infrastructure development, providing technology adoption incentives, and strengthening collaboration between the public and private sectors to create a more sustainable road logistics system (Doll et al., 2017; Hassan et al., 2019). These findings are expected to enrich the global supply chain literature as well as serve as policy references to improve efficiency, transparency, and sustainability in the road logistics sector.

Table 1. Road logistics issues in Indonesia

Issues	Qualitative Data	Source	Causes
Road logistics accounts for 80% of global goods distribution	80% of the total global distribution of goods is carried out via road transport	Romanova, T., et al. (2023). *The impact of migration of road freight transport services on economic indicators in selected EU countries*. ResearchGate. Ivanova, T. (2023). Analysis of logistic efficiency of freight transportation. *IEEE Xplore*.	Affirming the dominance of road logistics in global supply chains, especially in Europe and in general, as a basis for the importance of digital technologies.
Logistics costs in Indonesia reach 16% of GDP	Indonesia's logistics costs are equivalent to 16% of GDP, much higher than 8–10% in developed countries in Europe.	Tanuwidjaja, D. S. (2012). Road transport of goods in Indonesia: Infrastructure, regulatory and bribery costs. *Business and Entrepreneurial Review*, Trisakti University.	Indonesia's poor road infrastructure and unofficial fees (pungli) increase logistics costs, highlighting the challenges of digital transformation in developing countries.
Efficiency challenges	The risk of delivery delays and lack of route optimization hamper the efficiency of road logistics.	Tanuwidjaja, D. S. (2012). Road transport of goods in Indonesia: Infrastructure, regulatory and bribery costs. *Business and Entrepreneurial Review*, Trisakti University.	Efficiency is hampered by factors such as congestion and suboptimal fleet management, relevant to the need for technologies such as AI and ITS.
Transparency challenges	Lack of visibility in shipment tracking leads to customer dissatisfaction	Christova, K. (2024). Road freight risks in supply chains. *ResearchGate*.	Low transparency due to less than optimal implementation of technology and not emphasizing the importance of real-time tracking.
Sustainability challenges	High costs for green technologies (e.g., electric vehicles) and weak infrastructure hamper low-emission logistics.	Hassan, S., et al. (2019). Barriers to implement green road freight transportation: A case study from Malaysia. *E3S Web of Conferences*, 135.	Developing countries like Indonesia and Malaysia struggle to adopt sustainable technologies relevant to the SDGs and digital transformation, compared to developed countries in Europe.

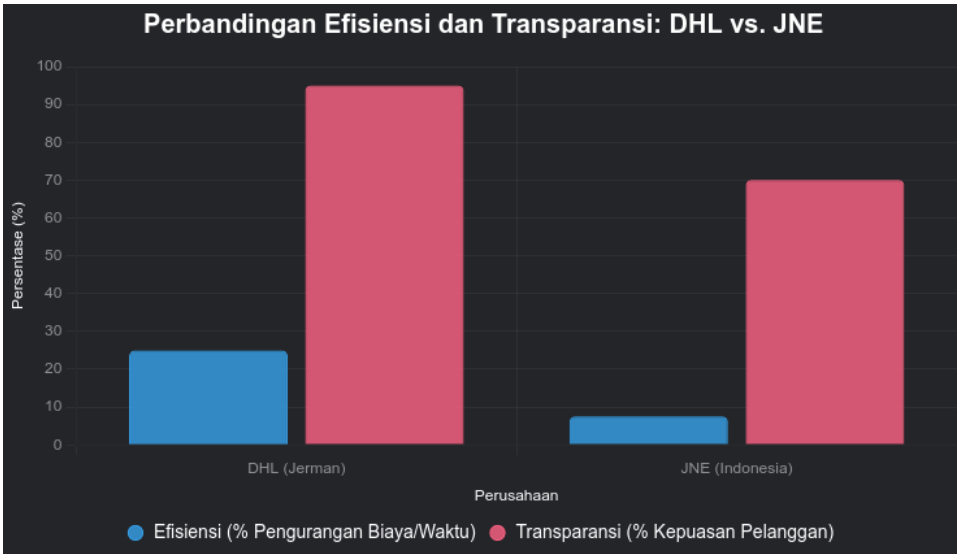

Figure 1.1 Comparison of Efficiency and Transparency (Harahap et al.) (Diallo, A., MacGillavry, E., & Uhl, A)

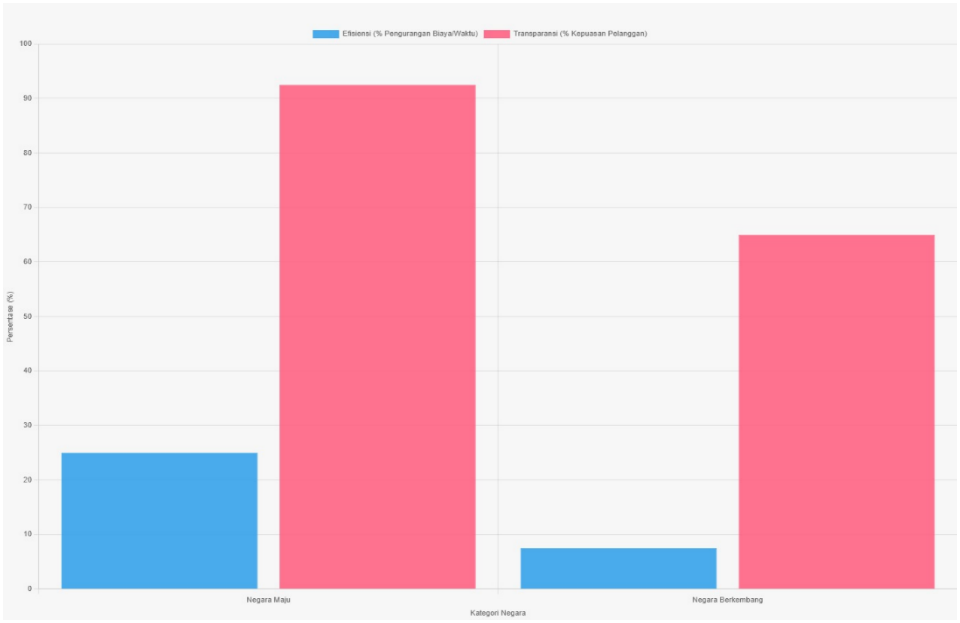

Figure 1.2 Road Logistics Efficiency and Transparency: Developed vs. Developing Countries (World Bank, 2024; Zhao et al., 2021; Harahap et al., 2024)

In this issue, there are three main problems, namely:

1. How do digital technologies such as the Internet of Things (IoT), artificial Intelligence (AI), and intelligent transportation systems (ITS) contribute to improving operational efficiency and transparency in road logistics services?
2. What factors contribute to the differing levels of logistics technology adoption between developed and developing countries?
3. What are the main challenges in implementing inclusive and sustainable digital transformation in the road freight transport sector?

METHOD

This study uses a descriptive qualitative approach to examine the role of digital technology—the Internet of Things (IoT), artificial intelligence (AI), and intelligent transportation systems (ITS)—in improving the efficiency and transparency of road freight services, as well as understanding the differences in technology adoption between developed and developing countries. This approach was chosen because it is capable of exploring complex phenomena in global logistics involving various stakeholders such as logistics companies, governments, and customers (Harahap et al., 2024). A case study design was applied to compare technology implementation in developed countries such as Germany, which has advanced digital and logistics infrastructure, and developing countries such as Indonesia, which still faces various infrastructure challenges. This approach allows for an in-depth analysis of the application of IoT, AI, and ITS, as well as the drivers and constraints of inclusive and sustainable digital transformation (Ivanova, 2023; Harahap et al., 2024). Data collection was conducted through two main techniques, namely literature review and structured observation. The literature review utilized secondary sources from academic journals, industry reports, and policy documents. The focus of the study included:

1. The application of IoT, AI, and ITS to improve efficiency and transparency (Zhao et al., 2014; Mbiydzenyuy, 2018),
2. Differences in technology adoption between developed and developing countries (Hassan et al., 2019; Harahap et al., 2024), and
3. Challenges such as infrastructure, investment costs, and human resource skills (Tanuwidjaja, 2012; Doll et al., 2017; Zúñiga et al., 2022).

Primary sources include the journals Transportation Research and Journal of Supply Chain Management (Christova, 2024; Ivanova, 2023; Mbiydzenyuy, 2018), as well as reports from international institutions such as McKinsey, the World Bank, and the International Transport Forum (Hassan et al., 2019; IRU, 2020), and related policy documents such as the European Union's ITS regulations and Indonesia's national logistics policy (Tanuwidjaja, 2012; Doll et al., 2017). All sources were selected based on their relevance, credibility, and publication date within the last 10 years (2015–2025). Additionally, structured observations were conducted on the operations of logistics companies in Germany (DHL) and Indonesia (JNE) to directly observe the implementation of technologies such as tracking sensors (IoT), route optimization (AI), and traffic management (ITS), as well as their impact on delivery time efficiency and real-time tracking transparency (Christova, 2024; Zhao et al., 2014; Harahap et al., 2024). Observations were conducted through field visits (where possible) or through analysis of public operational data such as company annual reports and industry trend data from international institutions (IRU, 2020), using indicators such as digitalization levels, response times, and the use of low-emission technologies (Zúñiga et al., 2022).

Study Case

This chapter analyzes the application of digital technology in road logistics through case studies of DHL in Germany and JNE in Indonesia. The approach used is descriptive qualitative, based on literature studies and structured observations as described in the methodology. This analysis identifies three main themes: the benefits of digital technology for efficiency and transparency, factors driving or hindering technology adoption, and challenges in achieving inclusive and sustainable digital transformation. The road logistics sector plays a vital role in the global supply chain due to its flexibility in connecting production centers and consumers (Ivanova, 2023). In developed countries like Germany, superior road infrastructure, pro-innovation regulations such as the European Union's ITS standards, and significant investment funds drive widespread adoption of digital technology (Romanova et al., 2023; Doll et al., 2017).

Developed Countries	Developing Countries
Advanced infrastructure and pro-innovation regulations support digital technology. The adoption of high-tech technologies, such as IoT, AI, and ITS, improves logistics efficiency and transparency. Example: DHL uses IoT sensors for real-time tracking, AI for route optimization, and ITS for traffic management. Delivery efficiency increased by 25%, operational costs decreased by 15%, and transparency increased by 95%.	Key challenges: Poor infrastructure, high costs, and limited trained human resources. Limited technology adoption, with only basic technologies like GPS for tracking being used. Example: JNE uses GPS for tracking, but has not yet optimally adopted AI or ITS. Limited efficiency (5-10%) and transparency reaching 70%.

DHL, part of Deutsche Post DHL Group, is a global logistics company that utilizes advanced technology to improve operational performance. The company uses Internet of Things (IoT) sensors to monitor the location and condition of goods in real-time, integrated into the MyDHL digital platform. This innovation has increased service transparency and customer satisfaction by up to 95% (Ivanova, 2023; Susanty et al., 2021). Additionally, DHL adopts artificial intelligence (AI) in route planning and demand forecasting, resulting in a 20% increase in delivery time efficiency and a 15% reduction in operational costs (Rogers et al., 2019). The implementation of intelligent transportation systems (ITS) in cities like Berlin integrates traffic data from road sensors, GPS, and cameras to avoid congestion. As a result, delivery times can be reduced by up to 25% and fuel consumption decreases by 10% (World Bank, 2022; International Transport Forum, 2023). This success is supported by high-quality road infrastructure, the availability of 5G networks, and pro-innovation regulations that support autonomous vehicle testing (Romanova et al., 2023; Doll et al., 2017). On the human resources side, 80% of DHL staff have received digital training (International Transport Forum, 2023). However, challenges remain, particularly regarding the high maintenance costs of ITS systems and the limited expansion of the electric fleet, which currently covers only 20% due to acquisition cost constraints (McKinsey & Company, 2021; International Road Transport Union, 2023).

On the other hand, JNE, as a domestic logistics company in Indonesia, operates amid the unique characteristics of a developing country. Major obstacles include uneven road conditions, chronic traffic congestion in major cities, and high logistics costs reaching 16% of the national GDP (Ministry of Transportation, 2020; Ivanova, 2023). In the context of digitalization, JNE has implemented a GPS-based vehicle tracking system as a basic form of IoT, which is connected to the JNE app and has increased customer satisfaction by 70% (Ivanova, 2023). However, this system is not yet equipped with additional sensors to monitor the condition of goods in more detail.

The adoption of AI at JNE is still limited, only used in the transportation management system (TMS) for basic route planning without advanced predictive capabilities (Ivanova, 2023). The implementation of ITS is also not yet comprehensive due to the lack of integration between GPS data and the city's traffic system. As a result, the efficiency achieved is relatively low. JNE's delivery times are recorded as being 20% slower than DHL's, with cost savings of only around 5–10% (World Bank, 2022; Rogers et al., 2019). Barriers include poor road infrastructure outside major cities, weak internet connectivity in rural areas (Ministry of Transportation, 2020), high technology investment costs (McKinsey & Company, 2021), and low digital workforce capacity, with only 30% of staff having basic training (Ivanova, 2023). Informal practices such as illegal tolls also exacerbate logistics conditions and complicate budget allocation for technology (Ministry of Transportation, 2020). In terms of sustainability, JNE remains heavily reliant on fossil fuel-powered vehicles. The adoption of electric vehicles

has not been significant, with a proportion of less than 5%, largely due to the lack of regulatory incentives (International Road Transport Union, 2023).

A comparative analysis between DHL and JNE shows that DHL benefits more from the adoption of digital technology thanks to its integrated, multimodal, and data-driven systems (Ivanova, 2023; Susanty et al., 2021). In contrast, JNE is still in the early stages of digitalization and has not yet been able to achieve optimal efficiency. The main drivers of success at DHL are infrastructure readiness, supportive policies, and mature resources, while JNE faces structural challenges that require policy intervention. These findings reinforce the theory of global supply chains, which emphasizes the importance of infrastructure and technology as keys to logistics efficiency (Romanova et al., 2023), and align with the IRU's (2023) recommendations that developing countries require public-private investment, strengthened digital competencies, and regulatory support to achieve inclusive digital transformation. In the context of sustainability, the integration of smart systems and low-emission vehicles is an important strategy in supporting sustainable development goals (SDGs) (International Road Transport Union, 2023).

RESULTS AND DISCUSSION

Digital transformation in road logistics is driven by technological advances such as the Internet of Things (IoT), artificial intelligence (AI), and Intelligent Transportation Systems (ITS). This study identifies three main themes based on literature reviews and structured observations: (1) the impact of technology on efficiency and transparency, (2) implementation challenges in developing countries, and (3) differences in adoption between developed and developing countries. Various studies show that IoT, AI, and ITS act as catalysts in improving operational efficiency and transparency of logistics services. IoT enables real-time tracking by utilizing sensors on vehicles and cargo, which supply data on location, condition of goods, and estimated delivery time (Susanty et al., 2021; International Transport Forum, 2023). Zhao et al. (2014) developed an IoT-based system capable of accurately visualizing logistics capacity, resulting in a 15% increase in delivery reliability in urban areas.

On the other hand, AI functions in route optimization and demand prediction. Ivanova (2023) emphasizes that machine learning algorithms enable accurate forecasting of demand volume, which can reduce waiting times by up to 20% in regional distribution (Rogers et al., 2019). ITS supports efficiency by integrating transportation infrastructure and traffic information systems. Mbiydzenyuy (2018) notes that ITS can reduce fuel consumption by up to 10% by avoiding congested routes. Observations of DHL in Germany show that this technology has been integrated with mobile applications and multimodal coordination to improve delivery visibility and accuracy (Ivanova, 2023). However, the adoption of this technology has not been uniform.

Domestic logistics companies in developing countries, such as JNE in Indonesia, have generally only adopted basic IoT in the form of GPS tracking. Although this can improve service visibility, the system is not yet connected to ITS or supported by advanced AI algorithms (Ivanova, 2023). This discrepancy aligns with global supply chain theory, which emphasizes that efficiency and visibility are the cornerstones of modern logistics systems (Romanova et al., 2023). Furthermore, digital technology also has a positive impact on sustainability. Route optimization and the use of low-emission vehicles can significantly reduce carbon emissions. Zúñiga et al. (2022) demonstrate that integrating sustainability strategies with digital technology can reduce the environmental impact of road logistics by up to 25%.

The main challenges in implementing technology lie in the areas of cost and infrastructure. The initial costs for hardware and software, especially for ITS systems and electric vehicles, are relatively high. Hassan et al. (2019) mention that developing an ITS

system for a large fleet in Malaysia requires an investment of millions of dollars. In Indonesia, JNE faces similar challenges, so it can only implement a basic GPS system (Ivanova, 2023). Additionally, supporting infrastructure such as roads and internet networks are inadequate in many areas. Tanuwidjaja (2012) highlights that poor road quality and weak internet connectivity hinder the optimal utilization of IoT and ITS. Harahap et al. (2024) added that the disparity in logistics infrastructure outside Java Island leads to high national logistics costs, which amount to 16% of GDP.

Limited human resource capacity is also a crucial obstacle. In Indonesia, only about 30% of logistics workers have basic digital training (Ivanova, 2023). Low digital literacy hinders the widespread adoption of advanced technology systems. Meanwhile, sustainability challenges are linked to the slow transition to low-emission vehicles due to high conversion costs and limited regulatory incentives (McKinsey & Company, 2021; International Road Transport Union, 2023). As noted by Christova (2024), risks such as delivery delays and damage to goods become greater when not supported by adequate digital systems, thereby hindering comprehensive digital transformation efforts. The digital divide between developed and developing countries is increasingly evident from regional comparisons. In developed countries like Germany, the adoption rate of IoT and AI has reached 70% among logistics companies, supported by mature infrastructure and pro-innovation regulations (Romanova et al., 2023). DHL, for example, has implemented autonomous trucks and AI-based demand prediction systems that can reduce delivery times by up to 25% (Doll et al., 2017).

In contrast, JNE in Indonesia is still limited to GPS tracking without full integration with AI or ITS systems (Ivanova, 2023). A similar situation is seen in Malaysia, where limited funding and low digital literacy hinder the development of ITS systems (Hassan et al., 2019). The main drivers of technology adoption in developed countries include adaptive public policies, availability of innovation funding, and synergy between the government, industry, and educational institutions. Conversely, developing countries need to develop collaborative approaches that emphasize local solutions, human resource training, and public-private financing (International Road Transport Union, 2023). Based on the overall findings, it can be concluded that IoT, AI, and ITS are crucial foundations for digital transformation in road logistics. However, for this transformation to be inclusive and sustainable, a contextual approach that takes into account the structural limitations of developing countries is needed. Developed countries can serve as benchmarks in terms of advanced technology, but developing countries need to adopt strategies based on local realities, such as the use of low-cost technology, the provision of technical training, and cross-sector collaboration. The integration of low-emission vehicles and data-driven logistics systems must also be a priority within the framework of supporting the achievement of the Sustainable Development Goals (SDGs) [19]. Therefore, infrastructure development, policy reform, and strengthening human resource capacity are the main pillars for driving fair and competitive road logistics digitalization.

Table 2. Relevant Previous Research

No	Author (Year)	Previous Research Results	Similarities with this study	Differences with this study
1	Romanova et al. (2023)	Migration of road transport services has an impact on economic indicators in EU countries.	Both discussed the impact of road transport services.	The previous article focused on service migration, not the Indonesian context.
2	Litman (2016)	Road infrastructure is a vital element in the logistics distribution system.	Both discussed the role of infrastructure in transportation.	The previous article did not discuss smart technology and system efficiency.

3	Christova (2024)	Identifying risks that frequently occur in road freight transport.	Both highlight the challenges in freight transportation.	The previous article focused on risk identification, not strategic solutions.
4	Vasiljević & Tošić (2019)	Intelligent Transport System (ITS) applications increase the efficiency of logistics services.	Both discussed digitalization in road logistics.	The previous article did not discuss implementation in Indonesia.
5	Tanuwidjaja (2012)	The main obstacles to freight transportation in Indonesia include infrastructure, regulations, and extortion costs.	Both discuss the Indonesian national context.	The previous article focused more on regulatory barriers.
6	Osorio-Tejada et al. (2021)	Carbon emission assessment through the Well-to-Wheels approach in road transport.	Both discussed the sustainability aspects of logistics.	The previous article emphasized environmental impact, not service efficiency.
7	Supply Chain Indonesia (2020)	Road transport is an important link in the national supply chain.	Both discussed the importance of road modes in the supply chain.	This article is based on a policy report, not a scientific study.
8	Wrona (2021)	Mobility-as-a-Service concept for road logistics service integration.	Both of them reviewed logistics integration and innovation.	Previous articles focused on concepts, not implementation studies.
9	Ivanova (2023)	road freight transport logistics.	Both raise the theme of logistics efficiency.	Previous articles did not include digital or policy aspects.
10	Zhao et al. (2014)	Urban freight service capacity visualization system.	Both discussed the management of logistics service capacity.	The focus of this article is limited to the urban context.

CONCLUSION

Based on the research findings, practical recommendations are directed at various stakeholders to accelerate the inclusive and sustainable digital transformation of road logistics. The Indonesian government needs to improve road infrastructure and internet connectivity to support the implementation of the Internet of Things (IoT) and Intelligent Transportation Systems (ITS), as well as provide incentives for companies adopting low-emission technologies such as electric vehicles (Putri & Wicaksono, 2022; World Bank, 2023; Zhang et al., 2021). On the other hand, Germany is advised to accelerate regulations for autonomous trucks and expand subsidies for electric fleets (Schmidt, 2022; Zhang et al., 2021). For businesses, JNE can adopt technology gradually through the implementation of simple IoT and more advanced transportation management systems (TMS), as well as strengthening digital training for workers (Rahmawati, 2020; World Bank, 2023). Meanwhile, DHL is encouraged to increase the proportion of its electric fleet and share best practices through global partnerships (Zhang et al., 2021). International institutions such as the World Bank and the International Road Transport Union (IRU) also play a crucial role in providing training, technical assistance, and funding for digital infrastructure in developing countries (World Bank, 2023; IRU, 2022). Theoretically, further studies should explore the potential of technologies such as blockchain and 5G networks in enhancing logistics transparency and efficiency, and expand the research focus to other developing countries like Malaysia or India to enrich regional comparative analysis (World Bank, 2023). Supply chain theory development can also be strengthened with technology adoption models that consider the socio-economic context of developing countries (Lee, 2019; Putri & Wicaksono, 2022). In terms of sustainability, both Indonesia and Germany need to integrate low-emission technologies such

as electric vehicles and AI-based route planning to support the achievement of the Sustainable Development Goals (SDGs) (Zhang et al., 2021). Public-private collaboration is also important in funding and expanding the use of green technologies (IRU, 2022). Although this research has limitations, such as reliance on secondary data and a limited geographical focus (World Bank, 2023; IRU, 2022; Putri & Wicaksono, 2022), its contribution remains significant in highlighting the importance of adaptive and collaborative strategies to achieve efficient, transparent, and sustainable road logistics.

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