ENHANCING SUSTAINABLE LOGISTICS THROUGH SMART TECHNOLOGY SOLUTIONS

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INTRODUCTION

Actuality. This article examines the impact of smart technology implementation on sustainable development practices within Polish logistics companies. In recent years, technologies supporting the optimization of logistics processes - such as route planning systems, real-time data analysis, and warehouse automation—have become increasingly important. The adoption of these technologies enables companies to manage resources more efficiently, while also reducing emissions and energy consumption.
The aim of this article is to investigate whether the adoption of such technologies correlates with higher levels of pro-environmental activities and greater commitment to corporate social responsibility (CSR), taking into account the specific characteristics of the Polish logistics market.
Research questions have been defined: To what extent are Polish logistics companies implementing smart technologies, such as route planning systems, Big Data analytics or warehouse automation, in response to increasing sustainability requirements? Is there a statistically significant relationship between the level of implementation of smart technologies and the extent of pro-environmental activities and CSR practices in the surveyed companies? How do the different characteristics of the surveyed companies (e.g., company size and market reach) affect the relationship between technology implementation and sustainability?
Research methodology. The study employed descriptive statistics, Spearman's rank correlation, linear regression, Fisher's Z transformation, and tests of normality and homogeneity of variance. Data were collected from 60 logistics companies, and selected through stratified random sampling based on company size, market of operation, and years of operation in the market. Indicators of technology use and sustainability were calculated to assess the extent of technology adoption and companies' commitment to sustainability. Building on this, statistical tests were performed to assess the strength and significance of the relationship between technology adoption and sustainability practices. Additionally, difference-in differences analyses were conducted between subgroups identified by company size and business scope to assess the impact of these characteristics on the relationship between technology adoption and sustainability.

Theoretical background

The concept of green logistics, rooted in sustainability theory, encompasses strategies aimed at minimizing the environmental impact of logistics activities (Nikseresht et al. 2024). Key elements, such as emissions reduction and transport optimization, have become increasingly feasible through the adoption of smart technologies (Tetteh et al. 2024). Achieving sustainability in logistics requires an integrated approach that combines operational strategies with modern technological solutions (Kawa & Pierański 2021). Research highlights that a critical factor in successfully implementing green logistics technologies is the proper adaptation of infrastructure and workforce preparedness, both of which remain significant challenges for the sector (Lin & Hu 2024; Zhao et al. 2022). Sustainability in logistics is an increasingly prominent topic in the literature, closely tied to regulatory, societal and economic pressures to reduce the TSL (Transport, Shipping, Logistics) sector's environmental footprint (Wang et al., 2019; Chung, 2021). Recent research has placed particular emphasis environmentally friendly on integrating strategies with advanced digital technologies, as innovations in this space have been shown to enhance supply chain management, optimize transport routes, monitor resource consumption and emissions, and improve data transparency (Ding et al., 2021).
This study is grounded in two complementary theoretical frameworks. First, innovation diffusion theory (Rogers, 2003) is applied, highlighting the role of innovation characteristics, stakeholder communication, socio-organizational context, and the evolving implementation process in the adoption of new technologies. In the logistics sector, this suggests that the uptake of smart technologies depends not only on their availability but also on stakeholder acceptance, organizational change readiness, and the alignment of technological solutions with business needs. Secondly, the study draws on literature related to Corporate Social Responsibility (CSR) and the Triple Bottom Line framework (Elkington, 1998), which emphasizes balancing environmental, social and economic factors. From this perspective, the implementation of sustainable technologies represents an investment in environmental performance, ethical supply chain practices, and long-term corporate reputation. Integrating these concepts positions technological innovation within a broader CSR strategy, where smart logistics serve as a means to achieve sustainability-driven objectives. By combining these two perspectives, this study postulates that greater adoption of smart logistics technologies will enhance both environmental performance and CSR initiatives.

Research results

The results of the linear regression analysis show a statistically significant positive relationship between the degree of smart technology implementation and the level of commitment to sustainability among the surveyed logistics companies (table 1).

Table 1. Analysis of the impact of smart technology deployment on sustainability commitment using linear regression

Variable	Coefficient	Standard error	T-statistics	P-value	Confidence interval 95%
Intercept	12.45	1.12	11.13	<0.001	[10.21, 14.69]
Technology Usage Score	0.63	0.15	4.20	<0.001	[0.33, 0.93]

Table 2 presents the results of the correlation analysis between the Technology Usage Score (TUS) and Sustainability Score (SS) indices across subgroups of companies, categorized based on the size of the organization and the scope of its operations. The purpose of this analysis is to assess how the specific characteristics of companies influence the strength and statistical significance of the observed relationship between technology deployment and commitment to sustainability.

Table 2. Relationship between TUS and SS in subgroups separated by size and scope of activity

Division of the sample by size	**N**	**r (TUS, SS)**	**P-value**
Small enterprises	33	0.38	<0.05
Medium-sized enterprises	17	0.56	<0.01
Large enterprises	7	0.65	<0.05
Very large companies	3	0.70	<0.10*
Division of the sample by business scope	**N**	**r (TUS, SS)**	**P-value**
National	20	0.44	<0.05
Regional	20	0.52	<0.01
International	20	0.58	<0.01

Division of the sample by size N r (TUS, SS) Small enterprises P-value 33 0.38 Medium-sized enterprises
The results indicate a positive correlation between smart technology deployment and sustainability across all subgroups. However, the strength and statistical significance of this relationship vary depending on the specific characteristics of the companies.
This suggests that regulatory pressures, greater stakeholder demands, or operational complexity of working across larger geographical areas may amplify the role of smart technologies in driving sustainability and CSR initiatives.
These findings provide a foundation for further research into the impact of contextual factors on the innovative and responsible practices of logistics companies.

Conclusions

This study confirms a significant positive relationship between the implementation of smart technologies and the extent of pro environmental and socially responsible activities in the Polish logistics sector. This trend is evident across both small and larger enterprises, as well as among companies operating at various geographical levels—from national and regional markets to the international stage. The findings suggest that organizations with greater resources and more complex international operations may be better positioned to leverage digital tools and automation, thereby translating technological innovation into enhanced sustainability and higher CSR standards.

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