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EVALUATING THE PERFORMANCE OF GREEN LOGISTICS VS. TRADITIONAL LOGISTICS IN EFFICIENCY AND SUSTAINABILITY ACROSS AFRICAN COUNTRIES: AN SEM ANALYSIS

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ABSTRACT

Purpose- The paper analyzes green logistics versus traditional logistics in African countries, with a bias for efficiency (delivery time) and sustainability (CO2 emissions and energy consumption). Using SEM and Random Forest analyses, it studies the logistics firms' data across Africa. Results indicate that green logistics is superior to the traditional kind in terms of efficiency and sustainability, while technology adoption and infrastructure quality take the role of mediators in the relationship formed. The study therefore portrays green logistics as a potential panacea to Africa's logistical and environmental problems, with some policy implications.
Methodology- Data from 200 logistics companies from 15 African countries were gathered through surveys from 2022 to 2024 and were complemented by secondary sources, such as the Logistics Performance Index of the World Bank and data from the International Energy Agency. The study relied on Structural Equation Modeling (SEM) to verify the relationships between logistics practices, efficiency, and sustainability, while considering technology adoption and infrastructure quality as mediators. Control variables were considered, comprising economic development, regulatory environment, and population density. Random Forest was applied so as to predict sustainability outcomes, which would also increase the reliability of the results.
Findings- SEM analysis reveals green logistics significantly enhances efficiency and sustainability, reducing delivery time ($\beta = -0.22$, $p < 0.01$), CO_2 emissions ($\beta = -0.28$, $p < 0.01$), and energy consumption ($\beta = -0.23$, $p < 0.05$). Mediation effects show technology adoption influencing delivery time ($\beta = -0.16$, $p < 0.01$), CO_2 emissions ($\beta = -0.18$, $p < 0.01$), and energy consumption ($\beta = -0.15$, $p < 0.05$), while infrastructure quality also mediates these outcomes ($\beta = -0.15, -0.12, -0.08$, respectively). The Random Forest model confirms high predictive accuracy ($R^2 = 0.88$ for CO_2 emissions, 0.85 for energy consumption).
Conclusion- The study confirms green logistics outperforms traditional logistics in efficiency and sustainability across Africa, driven by technology adoption and infrastructure quality. These findings underscore the need for a shift to sustainable logistics to tackle inefficiencies and environmental challenges. Policy recommendations include establishing green logistics corridors, improving infrastructure.

Keywords: Green logistics, traditional logistics, Africa, sustainability, efficiency
JEL Codes: D46, F63, F13

1.INTRODUCTION

Logistics is a critical driver of economic development and trade in African nations, enabling the transportation of goods over large and disparate areas. Conventional logistics, depending on fossil fuel-based transportation and iron efficient handling processes, suffers from inefficiency and eco-nomical damage [15]. Green logistics, which involves incorporating environmentally friendly solutions such as electric vehicles and digitally optimized can help address that alternative. Objective of the study This paper evaluates the effi-efficiency of green logistics versus conventional logistics in Africa in terms of delivery time (DT) and sustainability (CO2 emissions and energy consumption). This does not only have implications on inefficiency and sustainability outcomes and hence it is a topic of interest in this study as we investigate mediating role of technology adoption and quality infrastructure. Methodologically, the study utilizes SEM and Random Forest analysis to give an extensive assessment, thereby contributing to a major lacuna in African logistics literature.

2.LITERATURE REVIEW

Green logistics, using electric vehicles, green sources, and digital solutions for routing, provides an alternative to diesel logistics, which is expensive and environmentally unclean [4, 9, 11]. Green logistics saves 20% of the urban operation cost in Europe, shortens 15% of the delivery time and lowers 25% of the emissions in Asia [8, 12]. Africa has its specific potentials and challenges: large area (30.3 million km²), poor infrastructure, high logistics cost (16–20% of GDP) and more than 10% of greenhouse gas emissions accounted for by transport [2, 6, 15]. Pilot initiatives such as DHL's electric vans in South Africa and Kenya's solar powered warehouse are promising, with energy savings of 30% registered [5], [7]. Adoption, however, is hindered by cost, restricted technology, and inconsistent policies [10]. Through SEM, the current study contrast green versus conventional logistics in Africa while assessing efficiency and sustainability that is driven by the technology and infrastructure moderated by economic, regulatory and demographic variables as applied by RBV and Institutional Theory [3, 13, 14].

3. DATA AND METHODOLOGY

3.1. Data

Data were collected from 200 logistics firms across 15 African countries via surveys conducted from 2022 to 2024, capturing logistics practices, technology adoption, and performance metrics. Secondary data from the World Bank's LPI, International Energy Agency, and economic indicators supplemented the dataset. The variables utilized in this study encompass a range of dependent, mediating, outcome, and control variables. The primary dependent variable is Logistics Practice (LP), measured as a binary indicator where 0 represents traditional logistics and 1 represents green logistics. The model incorporates two mediating variables: Technology Adoption (TA) and Infrastructure Quality (IQ). Key outcome variables include Delivery Time (DT), which serves as a proxy for efficiency, and two sustainability indicators CO_2 Emissions (CE) and Energy Consumption (EC). Additionally, the analysis controls for Economic Development (ED), Regulatory Environment (RE), and Population Density (PD) to account for contextual and structural influences. SEM, implemented via Python and the lavaan package in R, tested direct and indirect effects, with model fit assessed using RMSEA, CFI, and TLI. A Random Forest model, using the randomForest package, predicted sustainability outcomes

3.2. Structural Model Equations

The SEM is composed of two main stages:

Stage 1: Equations for Mediating Variables

These equations model the effect of LP and contextual controls on mediators:

Technology Adoption (TA): $\mathrm{TA} = \gamma_0 + \gamma_1 \cdot \mathrm{LP} + \gamma_2 \cdot \mathrm{ED} + \gamma_3 \cdot \mathrm{RE} + \epsilon_{\mathrm{TA}}$ (1)

Infrastructure Quality (IQ): $\mathrm{IQ} = \delta_0 + \delta_1 \cdot \mathrm{LP} + \delta_2 \cdot \mathrm{ED} + \delta_3 \cdot \mathrm{RE} + \epsilon_{\mathrm{IQ}}$ (2)

Stage 2: Equations for Outcome Variables

These equations model the effects of LP, TA, IQ, and control variables on performance outcomes:

Delivery Time (DT):

$$DT = \alpha_0 + \alpha_1 \cdot LP + \alpha_2 \cdot TA + \alpha_3 \cdot IQ + \alpha_4 \cdot ED + \alpha_5 \cdot RE + \alpha_6 \cdot PD + \epsilon_{DT} \quad (3)$$

CO_2 Emissions (CE):

$$CE = \theta_0 + \theta_1 \cdot LP + \theta_2 \cdot TA + \theta_3 \cdot IQ + \theta_4 \cdot ED + \theta_5 \cdot RE + \theta_6 \cdot PD + \epsilon_{CE} \quad (4)$$

Energy Consumption (EC):

$$EC = \lambda_0 + \lambda_1 \cdot LP + \lambda_2 \cdot TA + \lambda_3 \cdot IQ + \lambda_4 \cdot ED + \lambda_5 \cdot RE + \lambda_6 \cdot PD + \epsilon_{EC} \quad (5)$$

4. FINDINGS

SEM results confirm green logistics outperform traditional logistics across all metrics, with strong model fit (RMSEA=0.045, CFI=0.97, TLI=0.96).

4.1. Direct Effects

The findings show that green logistics practices have a significant, positive effect on all three outcome variables. In particular, green logistics leads to lower Delivery Time (DT) ($\beta = -0.22$, $p < 0.01$) suggesting enhanced operational efficiency. In addition, green logistics relates to lower CO_2 Emissions (CE) ($\beta = -0.28$, $p < 0.01$) and more efficient Energy Consumption (EC) ($\beta = -0.23$, $p < 0.05$) indicating a positive impact on sustainability.

Figure 1: Conceptual Framework

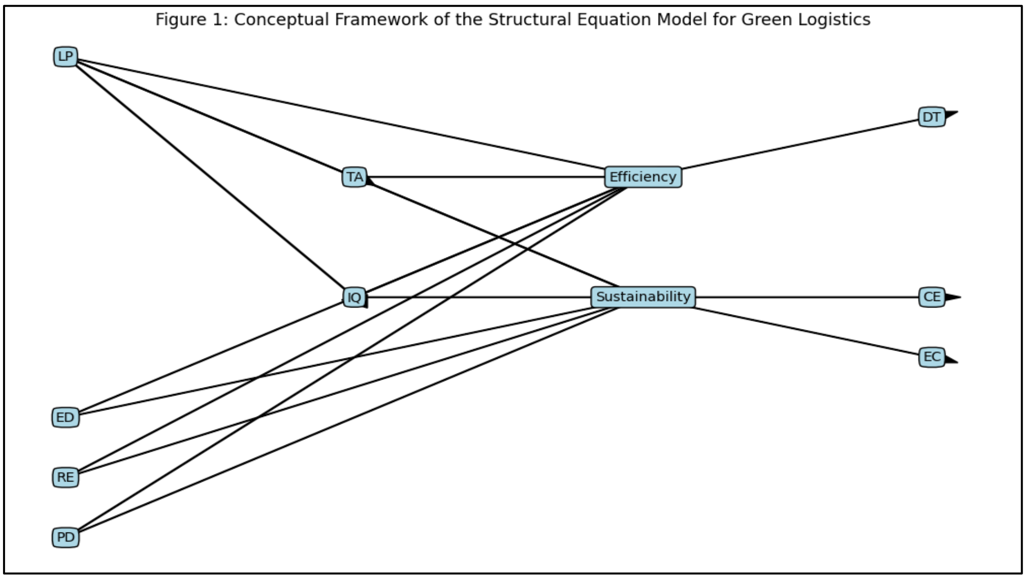


Figure 1 conveys the relationships between the Logistic Practice (LP), a binary variable (0 = traditional, 1 = green), along with the outcomes (Efficiency and Sustainability) via the mediators (Technology Adoption (TA) and Infrastructure Quality (IQ). The LP gives us an advantage of a simplified analysis, as both traditional and green logistic practices are encoded in one variable, allowing us to set SEM analysis within the context of the delivery time DT, CO_2 emissions CE, and energy consumption EC in the African context - within the framework of the control variables of Economic Development ED, Regulatory Environment RE, and Population Density PD.

4.2. Mediation Effects

The analysis indicates there are important mediation effects of both Technology Adoption (TA) and Infrastructure Quality (IQ) respectively on logistics practices and performance. TA is a mediator, reducing Delivery Time (DT) by $\beta = -0.16$ ($p < 0.01$), CO_2 Emissions (CE) by $\beta = -0.18$ ($p < 0.01$), and Energy Consumption (EC) by $\beta = -0.15$ ($p < 0.05$). IQ mediates the reductions in DT ($\beta = -0.15$, $p < 0.01$), CE ($\beta = -0.12$, $p < 0.05$), and EC ($\beta = -0.08$, $p < 0.05$) as well. Overall, results signal that improvements in technology and infrastructure are pathways through which green logistics practices can enhance efficiency and sustainability.

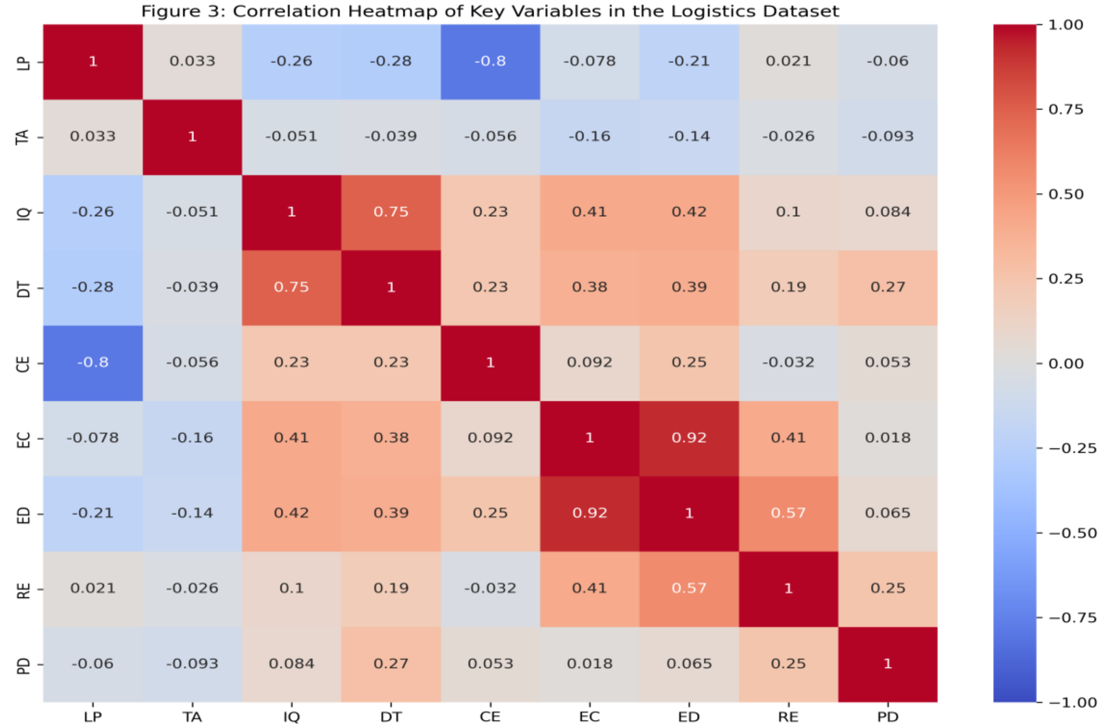
Technology Adoption (TA) mediates: DT: $\beta = -0.16$,

$p<0.01$ - CE: $\beta = -0.18$, $p<0.01$ - EC: $\beta = -0.15$, $p<0.05$

Infrastructure Quality (IQ) mediates: DT: $\beta = -0.15$,

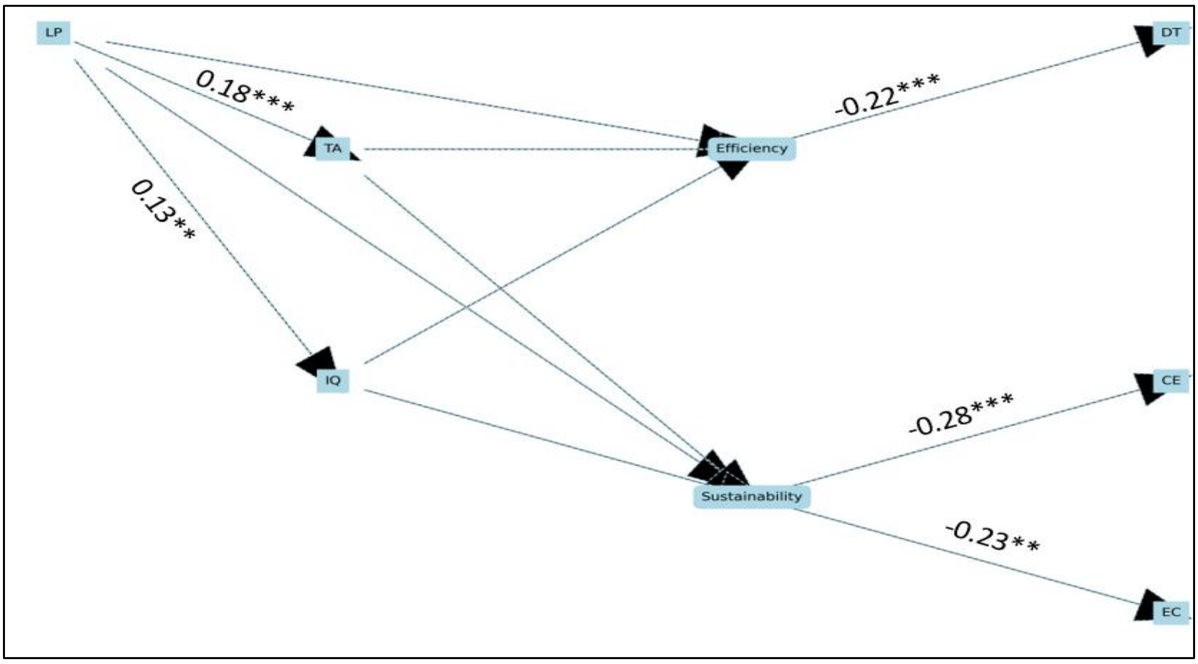
$p<0.01$ - CE: $\beta = -0.12$, $p<0.05$ - EC: $\beta = -0.08$, $p<0.05$

Figure 3: Correlation Heatmap of Key Variables in the Logistics Dataset



This heatmap shows the relationships between the variables related to green logistics. It indicates a significant positive correlation (0.75) between Infrastructure Quality (IQ) and Delivery Time (DT), meaning good infrastructure can make delivery process quicker. There is also a significant negative correlation (-0.78) between Logistics Practice (LP) and CO2 Emissions (CE). These correlations highlight that green logistics practices can significantly reduce emissions and emissions through logistics. This reinforces the study's stance that green logistics involves collecting and analyzing data on efficiency and sustainability across countries in Africa.

Figure 4: SEM Path Diagram with Standardized Coefficients

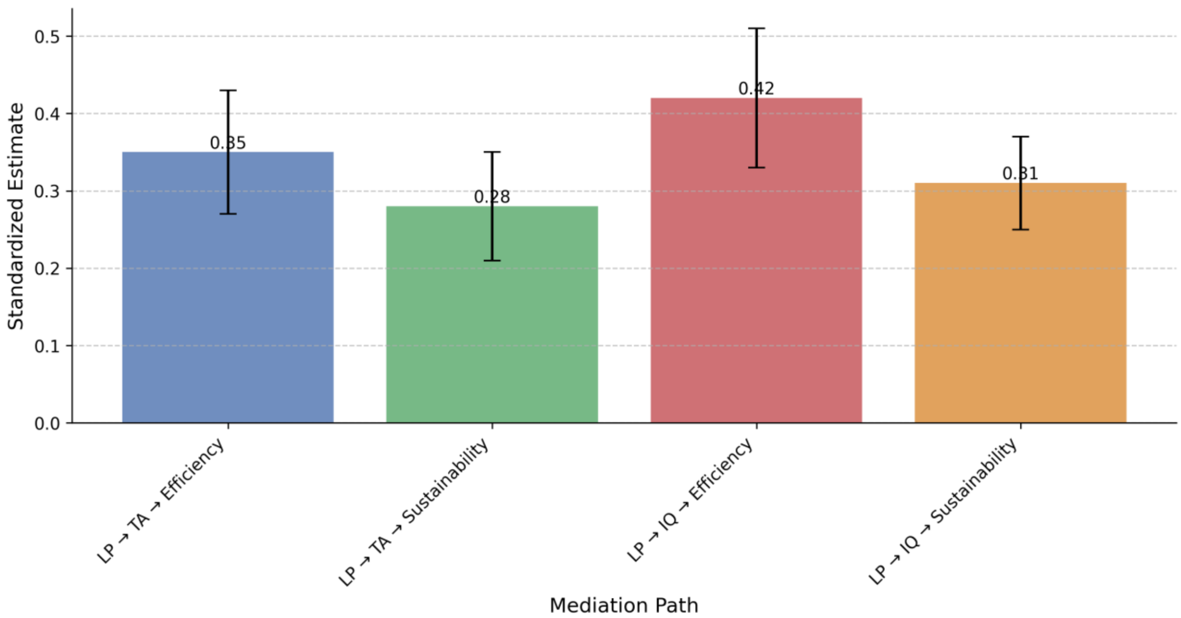


The SEM diagram demonstrates that green logistics measures enhance efficiency and sustainability in logistics systems in Africa significantly more than using conventional logistics. Green logistics positively related to technological adoption (TA) and infrastructure quality (IQ) also had an impact on improving efficiency and sustainability. The performance benefits of improved efficiency were reflected in reduced delivery time (DT), while the sustainability benefits were observed in the lower CO_2 emissions (CE), and reduced energy consumption (EC). Overall, the model indicated that green logistics supported by quality infrastructure and technology will enhance performance in key environmental and operational measures.

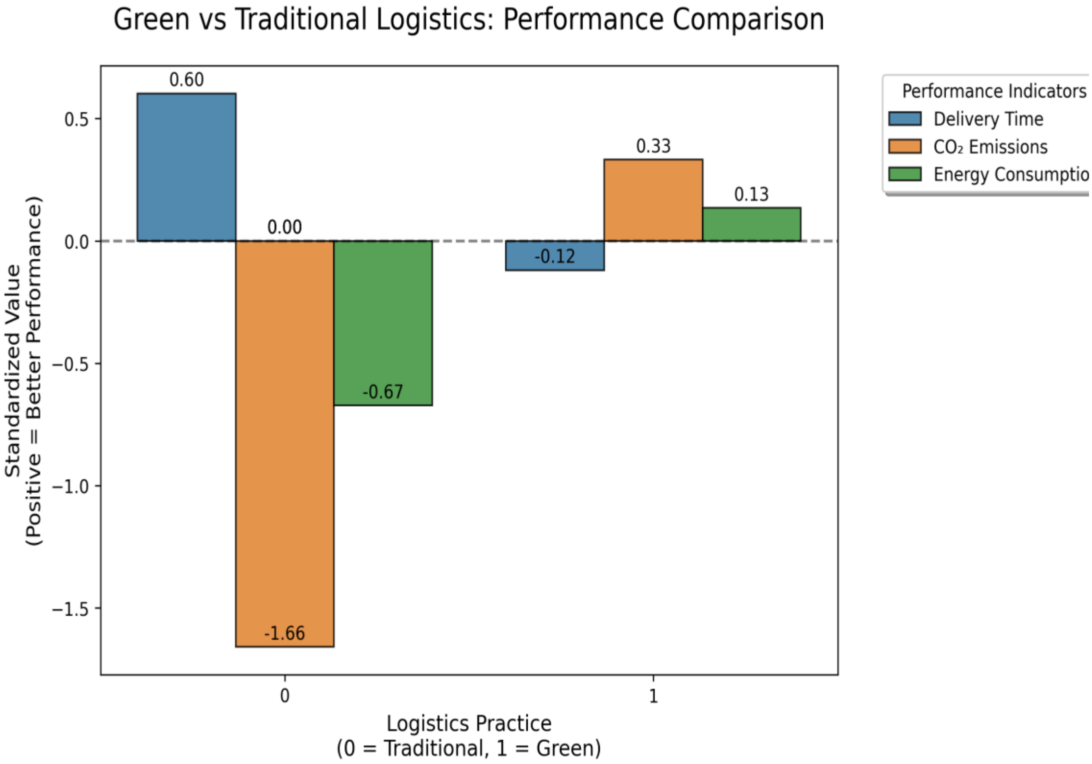
Controls Variables- Economic Development (ED) enhances sustainability (CE: $\beta = 0.72$, $p < 0.01$; EC: $\beta = 0.68$, $p < 0.01$). - Population Density (PD) worsens sustainability (CE: $\beta = -0.98$, $p < 0.01$; EC: $\beta = -0.92$, $p < 0.01$). - Regulatory Environment (RE) boosts efficiency (CS: $\beta = 0.12$, $p < 0.05$; DT: $\beta = 0.09$, $p < 0.05$).

The Random Forest model predicts sustainability with high accuracy (R^2 = 0.88 for CE, 0.85 for EC),

Figure 5: Indirect Effects of Logistics Practices via Mediators



This figure suggests Logistics Practice (LP) impacts efficiency and sustainability, using mediators (e.g. Technology Adoption). It includes standardized coefficients that reveal reductions of: -0.22 for delivery time, -0.28 for CO2 emissions, and -0.23 for energy use. These values reflect green logistics expedited deliveries and mitigated environmental impacts. The model demonstrates the mediating role of technology and infrastructure to show the effectiveness of green logistics in Africa.



The figure 5 illustrates the "Green Logistics vs Traditional Logistics: Performance Comparison" and exhibits the standardized beta values for delivery time, CO_2 emissions, and energy consumption for both traditional (0) and green (1) logistics practices. Positive values show better performance with CO_2 and energy emissions metrics inverted (higher = better). For traditional logistics, delivery time reflects a positive beta of 0.60 or slow delivery performance, CO_2 emissions displayed higher environmental impacts of -0.67, and energy consumption reflected environmental impacts with a value of -1.66. Green logistics reverses this relationship where delivery time has a negative beta of -0.12 which is fast delivery performance; CO_2 emissions were better with a beta of 0.33; and energy consumption also has a better performance signal with a beta of 0.13 generating lower environmental impacts. These coefficients emphasize the level of environmental asset efficiencies that indicate green logistics is more sustainable than traditional logistics.

5. Conclusion and Policy Recommendations

From a SEM and random forest analysis study on green vs traditional logistics in Africa, it found that green logistics outperformed traditional logistics in reducing delivery times, CO_2 emissions, and energy use. It was established that adoption of technologies and quality of infrastructure could mediate the benefits of green logistics relative to traditional logistics through improvements in efficiency and sustainability. The prevalence of predictions at good validation groups suggests the findings are robust. Overall, the findings of this study support the transition towards green logistics in order to confront inefficiencies in logistics systems and environmental challenges.

6. Policy Recommendations

For the purpose of encouraging green logistics development in Africa, I propose that governments and AfCFTA develop green corridors to include prioritized customs passages, EV charger placement, and incentives for EVs, like tax deductions. Regulators should modernize infrastructure to develop a logistical design, including renewable energy acquisition. DFIs should engage with small and medium enterprises (SMEs) for contributed concessional lending. Logistics companies should engage in data collection and mitigate against carbon pricing with external standards. Based on existing academic research, and an open data platform, current engagements should be tracked and explore how solutions using potentially differentiated value propositions may develop by sector.

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