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Unlocking greener supply chains: A global innovative perspective on the role of logistics performance in reducing ecological footprints

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A B S T R A C T

One of the significant challenges to achieveing the Green Supply Chain Management objectives is the ecological footprint associated with several logistics operations. In this study, we examine the impact of countries' logistics performance on environmental quality. For this purpose, the study collected data from a panel of 43 global economies over the period of 2010–2016. We used a composite index of logistics performance (LPI) to evaluate logistics performance and the ecological footprint (EFP) to assess environmental quality across diverse countries. Our results indicate that improvements in logistics performance are significantly associated with reductions in ecological footprints after controlling the effects of GDP, imports, exports, and adjusted net national income. These results are promising, and our findings highlight that although LPI initially intends to track the logistics performance without any consideration to the environmental concerns, most of its dimensions are indirectly capturing these concerns. These results compel policymakers to pay special attention to logistics performance, which is undoubtedly one of the most significant segments of global supply chains and may have the potential to make these supply chains greener and more environmentally friendly.

Introduction

Logistic performance serves as a leading indicator of the overall productivity of a country. It significantly contributes to evaluating the quality and performance of the overall supply chain (Rashidi & Cullinane, 2019). Logistics encompasses the planning and managing the flow of resources, including the coordination and movement of materials, goods, and products through the supply chain from acquisition to delivery (Khan et al., 2019). On the one hand, logistic activities play an imperative role in shaping the nation's economic progress by enabling the efficient movement of products. On the other hand, it critically impacts the environment (Khan et al., 2017; Magazzino et al., 2021). It is worth mentioning here that logistic activities produce massive amounts of greenhouse gas emissions (GHG), characterized by high energy demand (Rashidi & Cullinane, 2019; Umar et al., 2021). As per evidence, logistic operations account for approximately 22 % share in global air pollution, which is expected to grow in the near future (Rehman Khan et al., 2018). In addition, logistics infrastructure such as warehouses and distribution centers also deteriorate the environmental quality by impacting biodiversity and land use (Abdul et al., 2022).

Concerning the severity of logistic-induced environmental problems, various organizations and countries are under growing pressure to implement carbon management strategies in their logistic operations to offset the environmental effect or their logistic activities and improve the supply chain efficiency (Herold & Lee, 2017). In this stance, transitioning towards a green logistic (GL) or green supply chain (GSC) is considered desirable. Literature reveals growing evidence documenting that green logistics is crucial in limiting various environmental problems by reducing energy consumption and optimizing transportation routes (Freis et al., 2016). Green logistics primarily focuses on coordinating sustainable practices in transportation, inventory management, warehousing, and information exchange among supply chain partners. It aims to supply the products sustainably by improving the performance of logistic operations (Liu et al., 2018). Literature suggests that by implementing sustainable/green practices in logistics operations, nations can achieve sustainability in their supply chain operations because

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sustainable logistics is an integral part of the green supply chain (Rehman Khan et al., 2018; Yu et al., 2021). It is worth mentioning that the terms *"sustainable"* and *"green"* practices are frequently used interchangeably in the literature, as both generally aim to minimize environmental harm (Singh & Trivedi, 2016).

Notably, the origins of a sustainable/green supply chain can be traced back to Rao and Holt (2005), which was later developed further with the framework proposed by Carter and Rogers (2008). Green supply chain aims to reduce the environmental impact of a country's operations and protect the environment through sustainable practices. Researchers often use green logistics to measure green supply chain practices because logistics are one of the most critical areas that organizations or countries need to focus in order to improve their overall supply chain performance (Yu et al., 2021). However, there is still confusion surrounding the appropriate measure of green logistics.

The use of the Logistics Performance Index (LPI) as a measure of green logistics has been debated among researchers for a long time. LPI is a benchmarking tool that evaluates a country's logistics operations by using six indices, such as 1) *"customs clearance efficiency"*, 2) *"infrastructure quality"*, 3) *"ease of arranging* shipments", 4) *"logistics service quality"*, 5) *"tracking and tracing ability"*, and 6) *"shipment timeliness"*. Each index is evaluated on a scale of 1 to 5, with a score of 5 indicating outstanding performance and a score of 1 indicating poor performance. Some researchers argue that LPI is a measure of logistic performance and does not measure sustainability in logistic operations due to the lack of environmental considerations (Khan et al., 2017). However, several researchers are conducting their studies in the context of green logistics and supply chains by using various components of LPI (Anser et al., 2020; Karaduman et al., 2020; Liu et al., 2018; Liu et al., 2022).

However, it is essential to note that most of the researchers have tested the separate impact of each component of the LPI on the environment rather than using the composite index. We believe that using the composite index of the LPI will provide a more comprehensive assessment of a country's or region's logistics performance, which can impact the environment. This is because the composite index considers all dimensions of logistics activities, including *"customs clearance efficiency, infrastructure quality, ease of arranging shipments, logistics service quality, tracking, and tracing ability, and shipment timeliness"*. The score of this composite index is calculated after considering all six dimensions, providing a more holistic view of the logistics operations. A score close to 5 on the composite index indicates better performance in all six dimensions, while a score close to 1 indicates poor performance. In addition, the composite index allows for a more robust and statistically sound analysis and comparison of the logistics performance across different regions and countries. Therefore, consideration of the composite index of LPI is deemed appropriate to gain more insightful implications regarding the impact of logistic operations on the environment. However, when we look at the theoretical definitions of this index, we do not find evidence that the index was intended to capture anything related to green. However it can provide some insights into the sustainability of logistics operations because the component of this index is directly or indirectly related to environmental performance.

Research gap and contributions of the study

The relationship between logistics and environmental impact has been the subject of significant academic debate in recent years. Despite this growing attention, several critical research gaps remain that need to be addressed. First, most studies have focused on green logistics and supply chain operations at the firm or industry level, which limits our understanding of how logistics performance affects environmental quality at the country level. Addressing this gap is essential to grasp the broader environmental implications of logistics at a national scale. Second, there is ongoing debate among researchers regarding the most appropriate measure to capture green logistics and supply chain performance. A settled consensus on this issue is crucial for advancing the field and ensuring consistent methodologies across studies. Third, the literature presents conflicting findings on the relationship between logistics performance and environmental quality, with some studies reporting positive impacts and others reporting negative. Resolving these discrepancies is critical for establishing a clearer understanding of how logistics performance interacts with environmental variables. Fourth, prior research has typically examined individual components of the LPI rather than employing the composite index, which would provide a more integrated and holistic assessment of logistics performance across multiple dimensions. This gap in methodology limits the ability to comprehensively evaluate the full scope of logistics activities and their environmental impacts. Fifth, existing researchers have tested the effects of different dimensions of LPI on carbon emissions. While CO_2 emissions are a crucial indicator of climate change, they do not provide a comprehensive understanding of the full range of environmental consequences associated with logistics activities. CO_2 measurements focus narrowly on emissions from fossil fuel consumption, neglecting other critical environmental factors such as land use, water consumption, and biodiversity loss. This narrow focus limits the scope of analysis and overlooks the broader ecological impacts of logistics operations

In contrast, the Ecological Footprint (EFP) offers a more comprehensive and appropriate measure of environmental quality. Unlike CO_2, which focuses solely on atmospheric emissions, EFP assesses the total ecological demand on Earth by human activities, including logistics. EFP considers a broader range of environmental impacts, such as land use, water consumption, resource depletion, and habitat destruction, providing a more integrated view of sustainability. EFP also evaluates how much of the planet's biocapacity is consumed to support current economic and logistical activities, reflecting the overall strain on natural resources and ecosystems. By incorporating multiple environmental dimensions, including biodiversity loss and deforestation, EFP provides a more holistic assessment of the sustainability of logistics operations. However, as far as the author is aware, no prior studies have empirically explored the relationship between LPI and EFP, particularly at the national level, which leaves a significant gap in the literature. This significant gap in the literature highlights the need for a more comprehensive approach to understanding the environmental impact of logistics performance. We argue that the use of EFP as a broader and more holistic measure will capture a more complete picture of how logistics operations affect the environment

In light of the existing research gaps, addressing the relationship between logistics performance and environmental impact at a broader, national level has become increasingly urgent. Therefore, this study aims to investigate the relationship between the Logistics Performance Index (LPI) and environmental quality by utilizing a more comprehensive measure, the Ecological Footprint (EFP). By studying the relationship between LPI and EFP, this study contributes to the academic discourse and offers actionable insights for policymakers and governments. These findings will support the development of strategies and policies to improve logistics performance while simultaneously reducing the ecological footprint, thereby promoting economic efficiency and environmental sustainability. The overall theme of our study is presented in Fig. 1.

Literature review

Green logistic (GL) and environmental quality (EQ)

Green and sustainable logistics have received significant attention from researchers and policy makers in the field of environment and supply chain management. The research in this area was driven by the realization that unsustainable logistic operations constitute a significant share in raising environmental problems. For instance, Rehman Khan et al. (2018) reported that logistic-induced pollution substantially contributes to overall pollution. Khan (2019) stated that logistics activities, such as transportation and warehousing, generate emissions through burning fossil fuels, which releases greenhouse gases (GHG) into the

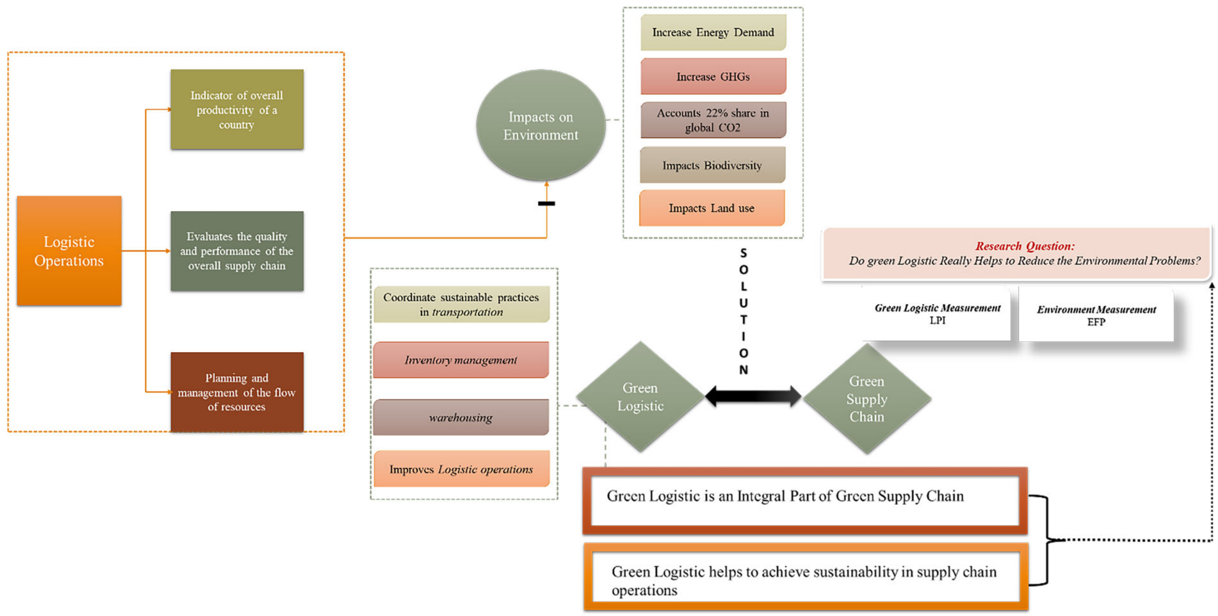

Fig. 1. Theme of the study; source: author's elaboration.

atmosphere and causes harm to the environment. Many other researchers also documented the significant linkage between logistic operations and the environment (Li et al., 2021; Sikder et al., 2022). (Peng, 2023) stated that unsuitable logistics wreak havoc on the environment while simultaneously triggering supply chain disruptions that dampen economic activity. Similarly, Lin et al. (2022) expressed concerns about the negative consequences of unsustainable logistics and supply chain practices. As a result of these findings, organizations and policymakers face increasing pressure to reduce the environmental footprint of logistics and supply chain operations by making them sustainable.

Currently, academicians are placing greater emphasis on exploring the effects of green logistics (GL) and green supply chain (GSC) practices on various environmental outcomes. Green logistics is frequently used as a critical indicator for measuring green supply chain practices. It represents one of the most crucial components organizations must prioritize to enhance their supply chain performance (Yu et al., 2021). Moreover, by using green logistics as a measure of green supply chain practices, researchers can assess the effectiveness of these practices in improving both logistics performance and environmental outcomes. Literature evident plethora of studies that report the significant linkage between green logistics (or green supply chain) and the environment at the firm or industry level (Fu et al., 2022; García Alcaraz et al., 2022; Laari et al., 2018; Lopes de Sousa Jabbour et al., 2017; Wang et al., 2018). However, there is a significant lack of research conducted at the country level, where the effects of green logistics and green supply chain practices have not been adequately explored. In addition to the limited number of studies at this scale, the existing research lacks consistency in how green logistics and green supply chains are measured, leading to challenges in drawing reliable conclusions across different contexts. One strand of studies reported that it is reasonable to use the logistic performance index (LPI) to capture the impact of green logistics on the environment because it includes several factors, such as customs and infrastructure, that can be related to the environmental impact of a country's logistics system. Another strand of researchers believes that LPI is not a comprehensive indicator of green logistics as it does not directly consider the environmental impact of a country's logistic system.

Liu et al. (2018) gathered annual data from the Asian Economies over the period of 2007–2016 and found that improvement in the logistic performance helped to mitigate the CO2 from a certain threshold. The study concluded that logistic operations, being an important component of green supply chain practices, help to promote environmental sustainability. Yu et al. (2021) tested the relationship between green logistics, energy demand, and environmental sustainability. The study used different indices of the logistic performance index (LPI), such as the *"ability to track goods, the ability and quality of logistics services, the arrangement of transportation with competitive prices, the efficiency of customs clearance, the timeliness of receiving goods, and the quality of trade and transportation related infrastructure"* to represent green logistic. After regressing the data of Asian Countries ranging from 2007 to 2016, the study found that LPI s significantly contributed to reducing energy demand and carbon emissions. It is argued that by improving logistic performance, economies can drive the adaptation of a green supply chain to mitigate various environmental costs. Ba-Alawi et al. (2024) did an interesting research. The authors explored green energy solutions in the context of energy and water supply systems. The primary aim of the study was to examine how integrating renewable energy-powered systems in supply chains could significantly reduce CO2 emissions. Their study demonstrated that incorporating green energy solutions in the supply chains led to a 46.79 % reduction in CO2 emissions.

Liu et al. (2022) believe that logistic operations are an essential component of supply chain performance which plays a critical role in mitigating various environmental risks. To prove this empirically, the study an analysis of the Asian Nations and tested the impact of LPI on CO2. The study confirmed that improvement in logistic performance leads to significant reductions in carbon emissions. Primadasa et al. (2024) also showed that logistic and supply chain improvements may result in significant environmental improvements.Suki et al. (2021) documented the negative correlation between LPI and CO2. The study confirmed that improvement in logistic performance significantly reduces logistic-induced pollution. Magazzino et al. (2021) emphasized the decarbonization of supply chain practices by improving logistic performance. The study documented that poorly managed logistic operation disrupts supply chain performance by increasing operational and environmental costs. However, Karaduman et al. (2020) utilized the data from Balkan countries and reported that a positive linkage exists between various indices of LPI and carbon emissions. The study stated that a higher amount of energy is consumed during logistic operations, raising the level of CO2. The authors suggested effective environmental management is crucial for ensuring a healthy environment and smooth functioning of logistic and supply chain operations.

Khan et al. (2019) conducted their research across the SAARC region and found a positive relationship between LPI and CO2. The study mentioned that LPI relies on fossil fuel incineration and non-renewable fuels, which harm economic welfare and environmental quality (EQ). Khan et al. (2017) combined the LPI with some environmental indices and tested their impact on economic growth and EQ. The findings of the study revealed that environmental LPI is a crucial determinant in boosting economic and environmental welfare. The study suggested a need to consider renewable sources in their logistics and supply chain operations to promote environmental sustainability. Mariano et al. (2017) developed a composite index of LPI and tested its impact on the carbon emissions produced by the transportation sector. The study found that improvement in overall logistic performance helps mitigate adverse environmental consequences. Khan et al. (2020) also documented the favorable impacts of logistic performance in improving overall EQ.

Based on the above literature, it is evident that the debate among researchers regarding the appropriate measure to assess green logistics and green supply chain operations remains unresolved. Some scholars advocate the use of the Logistics Performance Index (LPI) as a valid metric, while others express concerns due to its limited consideration of environmental factors. Furthermore, there are conflicting views on the actual impact of LPI on environmental outcomes, with some studies showing a positive influence while others raise doubts. These ongoing disagreements highlight the need for further research to clarify LPI's role. Based on this review, we propose to test the following research question:

Does logistic performance affect environmental quality?

To address this question, the corresponding null and alternative hypotheses are stated as follows:

H_0 (Null Hypothesis): *"There is no significant relationship between logistic performance and environmental quality."*

H_1 (Alternative Hypothesis): *"There exists a significant relationship between logistic performance and environmental quality."*

Conceptual framework

The conceptual framework of the study, shown in Fig. 2, is based on the theoretical foundations of the Resource-Based View (RBV) theory, initially proposed by Wernerfelt (1984) and further developed by Barney (1991). According to this theory, logistics performance can be considered a resource that enhances environmental quality and reduces a country's ecological footprint. The theory outlines three main channels: *efficient resource utilization, adoption of environmentally friendly technologies, and a shift towards sustainable transportation options*, through which logistics performance influences environmental quality.

Firstly, *efficient resource utilization* refers to optimizing critical resources such as fuel, energy, and time, which are central to logistics activities. Improved logistics performance enables organizations to better plan and execute logistics operations, significantly reducing resource wastage and inefficiency. For instance, logistics managers can reduce fuel consumption and minimize idle times for transport vehicles by optimizing transportation routes, consolidating shipments, and employing real-time tracking systems. Such practices lead to lower greenhouse gas emissions and a smaller carbon footprint, benefiting environmental quality (McKinnon et al., 2015). Additionally, the efficient use of warehouses, distribution centers, and fleet management systems reduces the overall energy consumption in the logistics chain. As logistics performance improves, organizations can cut down on excessive energy use, lowering operational costs and reducing environmental harm. By achieving higher resource efficiency, firms contribute to a more sustainable supply chain while enhancing their competitiveness in the market.

Secondly, adopting *environmentally friendly technologies* represents a key channel where improved logistics performance directly promotes sustainability. Organizations focusing on enhancing their logistics capabilities are more likely to invest in innovative, green technologies that minimize environmental impact. Examples include using electric vehicles, hybrid engines, and alternative fuels such as biofuels and hydrogen-powered trucks (Li et al., 2021). These technologies significantly reduce emissions, air pollutants, and dependency on fossil fuels. Moreover, advanced fleet management systems, eco-driving technologies, and automated logistics processes allow organizations to optimize fuel consumption and reduce their environmental footprint. Logistics companies that invest in such green technologies not only demonstrate environmental responsibility but also gain a competitive edge by positioning themselves as leaders in sustainability. Furthermore, this commitment to environmentally friendly technologies sends a signal to consumers and business partners about the company's sustainability goals, thereby attracting customers who value eco-friendly practices (Zhang et al., 2022). Over time, the widespread adoption of green technologies across the logistics sector creates a ripple effect, driving industry-wide innovation and pushing other organizations to follow suit in adopting more sustainable logistics solutions.

Finally, the *shift towards sustainable transportation options* is a vital channel through which improved logistics performance influences environmental quality. Traditional logistics operations often rely heavily on road transportation, which is associated with higher fuel consumption, air pollution, and carbon emissions. However, as logistics performance improves, organizations are able to make strategic shifts away from environmentally harmful transportation modes toward more

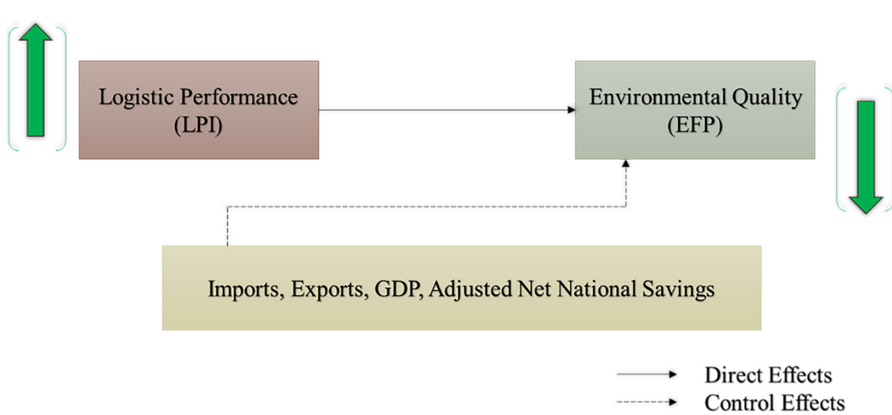

Fig. 2. Conceptual framework.
Note: The upward arrow for LPI indicates improved logistics performance, while the downward arrow for EFP suggests reduced ecological impact as LPI increases. The upward/downward green arrows show hypothesized relationships between LPI and EFP, i.e., when there will be an increase in LPI, there will be a decrease in EFP.

sustainable alternatives. For instance, companies can reduce their reliance on road transport by increasing their use of rail, sea, or multimodal transport systems, which are generally more energy-efficient and produce fewer emissions (Gu et al., 2022). Rail transport, for example, consumes less fuel per ton-mile than road transport and generates fewer pollutants, making it a more environmentally friendly option for long-haul freight.

Additionally, companies can employ route optimization technologies that allow them to choose less congested, shorter routes, thus further reducing fuel consumption and emissions. The shift to sustainable transportation options is further supported by adopting new logistics models, such as reverse logistics and circular supply chains, which focus on reducing waste and promoting the reuse of materials. By shifting towards these sustainable transportation modes, companies can significantly reduce their environmental footprint while maintaining or even improving logistics efficiency. Conclusively, resource view base theory argues that logistics performance is a valuable resource that can be used to improve environmental quality and reduce a country's ecological footprint. Through better use of resources, more environmentally friendly technologies and practices, and more sustainable transportation options, logistics performance can be leveraged to achieve a more sustainable future.

Methodology

Data and variables

To bring a novel perspective to the empirical relationship between logistic performance and environmental quality, we conducted our analysis at the country level, focusing on a sample of 43 global economies (see Table A1 in the appendix). These countries were selected for their diverse economic structures, stages of development, and logistical capacities, making them essential contributors to global trade and supply chains. This diversity is critical for capturing a wide range of logistical and environmental dynamics, allowing the study to provide more comprehensive insights. Focusing on these countries enables us to understand how logistics performance interacts with environmental quality across different national contexts, making the findings both globally relevant and policy impactful.

Unlike the previous studies, we use a composite index of logistic performance (LPI) to assess the performance of a country's logistic operations and ecological footprint (EFP) to gauge the environmental quality. In addition to this, we also use some control variables such as "imports of goods and services, exports of goods and services, GDP, and adjusted net national income per capita" to avoid possible econometric errors. All these variables are measured in constant 2015 US$ to ensure comparability across years and economies. The data of ecological footprint was obtained from the global footprint network, while the data of the remaining variables were extracted from the World Bank. A detailed description of the core study variables is presented in Appendix, Table A2.

Notably, the study covers the time period from 2010 to 2016, as this was the most recent period for which complete and consistent data was available for all sets of variables. Although more recent data existed for variables such as imports, exports, GDP, and net national income per capita. The data of LPI was only consistently available up to 2016. Given that our primary objective is to assess the impact of LPI on environmental quality, it was crucial to ensure data consistency across all variables. Therefore, we limited the analysis to the years for which complete and reliable LPI data was available. This allows for a more robust and accurate analysis, ensuring that the results reflect the true relationship between logistics performance and environmental outcomes.

Econometric model building

The basic econometric model of the study is presented in Eq. (1).

$$EFP_{it} = LPI_{it} + IMP_{it} + EXP_{it} + GDP_{it} + Adj.NNI_{it} + u_{it.} \quad (1)$$

Where *EFP* is the ecological footprint measure in global hectors (proxy of environmental quality), *LPI* is the logistic performance index (proxy of country's logistic operations), exports (*EXP*), imports (*IMP*), gross domestic product (*GDP*) and adjusted net national savings (*Adj.NNI*), which are measured in constant 2015 US dollars. u is the stochastic error term, which is assumed to be normally distributed. i is individual nations, and t denotes the time.

Since all the chosen study variables are in different units, we have transformed our variables into their natural logarithmic form to improve the accuracy and robustness of the results (Shahbaz et al., 2022; Tao et al., 2022; Wang et al., 2022). The econometric form of our transformed variables is presented in Eq. (2).

$$lnEFP_{it} = lnLPI_{it} + lnIMP_{it} + lnEXP_{it} + lnGDP_{it} + lnAdj.NNI_{it} + u_{it.} \quad (2)$$

Baseline econometric approach

The present study applies a pooled regression model to estimate the empirical relationship among the relevant study variables. Pooled regression is a method of analyzing panel data, which is data that includes observations of multiple individuals or entities (such as firms or countries) over time. It is a simple and useful method for analyzing panel data when the assumptions of homoskedasticity, independence errors, and time-invariant variables are held. It provides a simple and efficient way to estimate the overall relationship between the dependent and independent variables across all observations. It also provides feasible results for the case of small datasets.

Empirical results

Descriptive statistics

Our analysis begins by calculating descriptive statistics across different subgroups, categorized by income levels and geographical regions, to provide a comprehensive overview of the stylized facts. Analyzing the data in this manner is essential because it helps us to detect whether logistics performance and environmental quality show similar patterns or vary across different economic conditions and regions. Understanding these variations is crucial for tailoring insights and recommendations for countries with different economic structures or geographical challenges. This subgroup analysis allows us to examine if there is heterogeneity or homogeneity in the data. This sheds light on how logistics and environmental impacts differ across income levels and regions.

The results of descriptive statistics are presented in Tables 1-3. Table 1 reports the overall summary statistics for the 43 countries in the sample, showing critical measures like the mean, maximum, minimum, standard deviation, skewness, and kurtosis for each variable. Table 2

Table 1
Descriptive statistics.

	Mean	Std. Dev.	Minimum	Maximum	Skewness	Kurtosis
EFP	17.453	1.436	14.932	21.160	0.618	2.791
LPI	1.066	0.133	0.713	1.372	−0.259	2.575
IMP	24.254	1.395	20.837	27.002	−0.123	2.604
EXP	24.096	1.621	20.298	26.814	−0.310	2.453
GDP	25.065	1.562	21.150	28.454	−0.030	2.663
ADJ. NNI	9.086	2.875	6.543	24.484	4.402	23.912

Source: Author's calculations.

Table 2
Descriptive statistics – income wise.

	Mean	Std. Dev	Minimum	Maximum	Skewness	Kurtosis
High income						
EFP	17.235	19.120	0.904	15.920	0.528	2.401
LPI	1.180	1.422	0.096	1.019	0.630	3.227
IMP	24.762	26.868	1.037	23.178	0.459	2.056
EXP	24.828	27.033	1.063	23.216	0.499	2.162
GDP	25.395	27.223	1.037	23.690	0.013	1.735
ADJ. NNI	9.594	10.703	0.499	8.677	0.585	2.659
Low income						
EFP	17.108	17.564	0.253	16.732	0.482	2.671
LPI	0.851	1.061	0.205	0.469	−0.889	2.665
IMP	23.238	23.710	0.512	22.500	−0.556	1.593
EXP	23.132	24.644	1.289	21.534	−0.110	1.298
GDP	24.258	24.867	0.550	23.459	−0.321	1.653
ADJ. NNI	8.943	24.484	5.212	6.543	2.642	8.036
Lower middle income						
EFP	17.993	21.160	1.610	14.932	0.053	2.595
LPI	0.970	1.230	0.124	0.713	0.041	2.275
IMP	23.993	27.002	1.612	20.837	−0.010	2.575
EXP	23.616	26.814	1.814	20.298	0.010	2.297
GDP	25.137	28.454	1.795	21.150	−0.314	2.956
ADJ. NNI	8.393	8.997	0.363	7.627	0.032	2.089
Upper middle income						
EFP	17.774	22.380	2.020	15.509	0.873	2.910
LPI	1.042	1.298	0.131	0.791	0.524	2.244
IMP	24.047	26.693	1.524	21.962	0.345	1.767
EXP	23.831	26.724	1.830	21.214	0.229	1.652
GDP	25.201	30.101	2.130	22.588	0.769	2.696
ADJ. NNI	9.046	24.484	2.795	6.543	4.530	25.353

Source: Author's calculations.

Table 3
Descriptive statistics – region wise.

	Mean	Std. Dev	Minimum	Maximum	Skewness	Kurtosis
East Asia & Pacific						
EFP	18.793	22.380	1.726	15.952	0.618	3.196
LPI	1.126	1.422	0.190	0.726	−0.348	2.211
IMP	25.221	26.868	1.504	22.117	−0.965	2.364
EXP	25.221	27.033	1.674	21.735	−1.002	2.481
GDP	26.338	30.101	1.834	23.017	0.258	3.083
ADJ. NNI	25.221	27.033	1.674	21.735	−1.002	2.481
Europe & Central Asia						
EFP	17.104	20.486	1.272	15.509	0.967	3.492
LPI	1.060	1.290	0.118	0.791	−0.048	2.056
IMP	23.976	26.693	1.174	21.962	0.413	2.692
EXP	23.836	26.724	1.387	21.214	0.069	2.525
GDP	24.744	27.961	1.348	22.588	0.571	2.857
ADJ. NNI	23.836	26.724	1.387	21.214	0.069	2.525
Middle East & North Africa						
EFP	17.280	19.120	0.752	16.142	0.978	3.335
LPI	1.098	1.372	0.168	0.469	−1.424	6.332
IMP	24.407	26.367	1.072	22.500	0.475	2.295
EXP	24.367	26.646	1.322	21.534	−0.104	2.474
GDP	25.240	27.223	1.050	23.459	0.343	1.986
ADJ. NNI	24.367	26.646	1.322	21.534	−0.104	2.474
South Asia						
EFP	18.020	21.160	1.938	14.932	0.054	2.291
LPI	0.965	1.230	0.129	0.713	0.075	2.427
IMP	23.873	27.002	1.889	20.837	−0.005	2.384
EXP	23.363	26.814	2.100	20.298	0.077	2.090
GDP	25.093	28.454	2.199	21.150	−0.375	2.397
ADJ. NNI	23.363	26.814	2.100	20.298	0.077	2.090

Source: Author's calculations.

breaks down the statistics by income level, such as high-income, low-income, lower-middle-income, and upper-middle-income groups. Table 3 focuses on regional breakdowns, including regions like East Asia & Pacific, Europe & Central Asia, and South Asia.

Table 1 shows the Logistics Performance Index (LPI) has a mean value of 1.066 with a standard deviation of 0.133, suggesting that logistics performance is relatively consistent across countries in the sample. The Ecological Footprint (EFP) has a mean of 17.453, with moderate variability indicated by a standard deviation of 1.436. These overall values provide a general sense of the dataset, but they obscure important heterogeneity that becomes clearer when we break the data down by income level and region.

Table 2 shows significant heterogeneity across different income groups. High-income countries show a much higher average LPI (1.180) than low-income countries (0.851). This reflects substantial disparities in logistics infrastructure and efficiency between wealthier and poorer nations. Regarding environmental impact, lower-middle-income countries report the highest average EFP (17.993), indicating that they face greater environmental pressures. High-income countries, by contrast, have a slightly lower average EFP (17.235), likely due to more effective environmental management

Moreover, other economic indicators such as GDP, IMP, EXP and ADJ.NNI also shows considerable variation, with high-income countries reporting much more robust financial performance. The difference in these indicators signifies the heterogeneity in logistics and environmental performance across income groups, suggesting that the relationship between logistics performance and environmental quality is not uniform but varies according to economic status.

Table 3 reports descriptives region-wise, and the variation or heterogeneity among results becomes even more evident. For instance, the East Asia & Pacific region exhibits the highest average Ecological Footprint (EFP) of 18.793, compared to Europe & Central Asia, where the EFP is lower at 17.104. This suggests that East Asia & Pacific countries face more significant environmental pressures, likely due to higher levels of industrial activity, urbanization, and resource consumption. In contrast, Europe & Central Asia may benefit from more stringent environmental regulations or more sustainable practices, contributing to their relatively lower environmental impact. Similarly, logistics performance, as reflected by the Logistics Performance Index (LPI), varies significantly across regions. The East Asia & Pacific region reports a higher LPI (1.126), indicating more advanced logistics infrastructure and greater efficiency in managing supply chains, while South Asia shows the lowest LPI (0.965), highlighting logistical inefficiencies that may stem from underdeveloped infrastructure or less effective policy frameworks. These disparities in LPI across regions highlight the differences in how well countries can optimize their logistics systems to balance economic growth with environmental sustainability. The variability in GDP, IMP, EXP, and ADJ.NNI across regions further signifies the heterogeneity in financial and logistical capacities, with some regions better equipped to manage logistical challenges and their environmental impact than others.

Regression output and discussion

This study uses pooled regression analysis to test the hypothesized relationship among the underlying variables. The outcomes of the study are reported in Table 4. The study found that logistic performance negatively impacts ecological footprints. The result implies that a 1 % increase in LPI leads to a 1.944 % decline in EFP. This finding is consistent with the existing literature and suggests that improvements in a country's logistics operations are beneficial for environmental quality (Liu et al., 2018; Liu et al., 2022; Suki et al., 2021; Yu et al., 2021). The negative relationship highlights that countries with more efficient logistics systems can significantly reduce their environmental impact by

Table 4
Impact of LPI on ecological footprint (EFP): global evidence.

Variables	Coefficient
Intercept	−4.931***
LPI	−1.944***
IMP	0.448***
EXP	−0.416***
GDP	0.961***
Adj.NNI	−0.053***
R^2	0.844
Adjusted R^2	0.842

Note: "*** shows that results are significant at the level of 1 %"; Source: Author's calculations.

optimizing resource use, minimizing waste, and adopting cleaner technologies. This improvement in logistics performance typically leads to more efficient transportation routes, reduced fuel consumption, and lower greenhouse gas emissions, all of which enhance environmental outcomes (Yu et al., 2021).

Moreover, as LPI increases, it often signals better logistics performance, encouraging the adoption of environmentally friendly practices, such as eco-friendly technologies and sustainable transportation solutions. This shift further reduces the environmental impact of logistics activities (Liu et al., 2022). In addition, an increase in LPI can also promote stronger regional and worldwide collaboration (Önsel Ekici et al., 2016). Countries with high LPI are often viewed as reliable and efficient trade partners. This can result in the formation of new trade deals and increased cross-border cooperation in the logistics sector, which helps minimize the nation's ecological footprint by reducing travel distance and improving the effectiveness of global supply chains by promoting international trade and cooperation. The above arguments are sufficient to justify the significant relationship between LPI and EFP. Hence, the H_1 is accepted.

The outcomes of Table 4 further reveal the favorable impact of Adjusted NNI on environmental quality. Results imply that 1 % increase in Adj.NNI leads 0.053 % decline in the EFP. This is so because the rise in adjusted NNI is a measure of economic welfare that leads to a corresponding increase in the country's adjusted net savings, which can be used to fund environmentally friendly and renewable projects that reduce the environmental impact of many economic activities (Larissa et al., 2020). Moreover, an increase in adjusted NNI can improve the standard of living for individuals, enabling them to prioritize environmental quality and support environmental protection initiatives that minimize the carbon impact of consumption activities and hence improve the EQ. Results are aligned with (Larissa et al., 2020; Zhang & Zhang, 2018).

In addition, an increase in imports is found to have a negative effect on EFP, as it transfers emissions from the importing country to the exporting country. This phenomenon, often referred to as "carbon leakage," occurs when goods are produced in countries with less stringent environmental regulations, leading to higher emissions during production (Al-Mulali & Sheau-Ting, 2014; Mahmood et al., 2020). As a result, while importing countries benefit from lower emissions within their own borders, they indirectly contribute to global emissions by consuming products from countries with weaker environmental standards. This highlights the environmental costs associated with globalization and the need for more stringent international environmental agreements to mitigate such effects. On the other hand, an increase in exports is found to have a positive impact on environmental quality. This is likely because countries that specialize in exports tend to adopt more efficient production processes and advanced technologies, leading to lower emissions per unit of output (Wang et al., 2020). Export-driven economies often focus on industries where they have a competitive advantage, enabling them to produce goods more efficiently and with less environmental harm. Furthermore, as countries become more integrated into global trade networks, there is greater pressure to comply with international environmental standards, which can lead to the adoption of more sustainable production practices. This suggests that when managed effectively, exports can help reduce environmental impact by promoting greener technologies and more efficient production methods.

Conclusion, policy implications, and future research directions

Logistics operations are a fundamental driver of economic development, yet their contribution to environmental degradation is a significant concern. With increasing global awareness of environmental issues, the interplay between logistics and sustainability has emerged as a critical area of academic inquiry. While a substantial body of research exists on green logistics and sustainable supply chains, there remains debate surrounding the appropriate metrics for measuring sustainability in logistics. A common approach among researchers is to employ the Logistics Performance Index (LPI), even though it was not initially designed for this purpose. The LPI framework primarily focuses on operational efficiency, though specific components, such as infrastructure quality and the ease of arranging shipments, have indirect implications for environmental outcomes. These components offer valuable insights into the sustainability of logistics practices.

In this study, we empirically examined the relationship between logistics performance and environmental quality using the Ecological Footprint (EFP) as a comprehensive measure of environmental impact. Unlike previous studies that predominantly focused on carbon emissions, our analysis employed EFP to capture a broader spectrum of environmental effects, including resource depletion and land use. Based on data from 43 global economies spanning the years 2010 to 2016, our findings indicate that improvements in LPI are associated with reductions in the Ecological Footprint. This result aligns with existing literature, which suggests that enhancing logistics efficiency can contribute positively to environmental sustainability. Notably, while the LPI was not explicitly designed to measure environmental outcomes, it still offers valuable insights into sustainable logistics practices. Our results demonstrate that higher LPI scores, indicating better logistics performance, are linked to lower ecological footprints. It suggests that improving logistics efficiency can have environmental benefits.

Based on the results, we suggest the following policy suggestions. First, governments should actively provide financial incentives, such as subsidies, tax breaks, or low-interest loans, to logistics companies that adopt greener technologies and sustainable practices. These financial incentives can be crucial in overcoming the high upfront costs associated with green technology investments, making eco-friendly solutions more accessible and cost-effective for businesses. Such policies would also encourage the transition to cleaner vehicles, energy-efficient infrastructure, and smart logistics systems that optimize routes and reduce fuel consumption. By lowering the financial burden of adopting green logistics practices, these incentives can create a more sustainable logistics sector while simultaneously supporting economic competitiveness. Second, stricter environmental regulations are essential to ensure that logistics activities are conducted within a sustainability framework. Governments should implement clear and enforceable emission standards, particularly for high-polluting logistics operations such as freight transportation and warehousing. These regulations could include mandatory emission caps, fuel efficiency requirements, and waste management protocols for logistics firms.

Additionally, governments should encourage transparency by requiring companies to report their environmental performance, which could be tied to a certification system that distinguishes sustainable logistics operators from their competitors. These regulations drive the sector toward more sustainable operations and create a competitive advantage for companies that invest in eco-friendly logistics, meeting regulatory requirements and consumer demand for greener services. Third, governments should prioritize research, development, and innovation in green logistics technologies. This includes facilitating public-private partnerships aimed at developing and deploying renewable energy sources, such as electric vehicles, solar-powered warehouses, and other sustainable logistics solutions. Governments can play an instrumental role by investing in infrastructure, such as charging stations for electric vehicles and intelligent transportation systems, which would support logistics companies in transitioning to greener alternatives.

Furthermore, public investments in research can stimulate breakthroughs in new technologies that can minimize environmental impacts, from more efficient freight management systems to biodegradable packaging materials. Fourth, fostering collaboration between logistics companies and environmental organizations is crucial to raising awareness and promoting the exchange of knowledge on sustainable practices. This can involve creating platforms where companies can share best practices, lessons learned, and new sustainability innovations. Governments could support these collaborations through grants and incentives for joint sustainability projects, helping logistics companies innovate in environmentally and economically beneficial ways. Fifth, sustainability certifications should be introduced and promoted within the logistics industry. Certifications would provide an objective benchmark for companies to measure and improve their sustainability efforts, and companies holding these certifications could benefit from enhanced brand reputation, access to green financing, and increased customer loyalty. This policy encourages companies to adopt eco-friendly practices and signals to consumers and business partners that certified companies are committed to environmental stewardship.

While this study provides valuable insights into the relationship between logistics performance and environmental sustainability, it has several limitations that the forthcoming researchers should address. First, our analysis is based on a unique global dataset spanning 43 economies from 2010 to 2016. It does not delve into region-specific or income-level differences in logistics performance and environmental impact due to insufficient data availability. These factors could significantly influence the results, as countries with differing levels of economic development, infrastructure quality, and environmental regulations may exhibit varying relationships between logistics efficiency and sustainability. Future research should focus on conducting region- and income-specific analyses to better understand how logistics operations affect environmental quality across different contexts. Such studies could offer targeted insights for policymakers, enabling them to craft more localized solutions that address the unique challenges faced by different regions. Second, we used the EFP to measure the environmental impact in this study. While EFP provides a broader perspective than carbon emissions alone, future researchers might consider using other environmental indicators or composite indices, such as the environmental performance index (EPI), or global green growth index (GGGI) to measure sustainability.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used AI-assisted technologies to improve language. After using AI-assisted technologies, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Haoyu Cheng: Writing – original draft, Project administration, Methodology, Conceptualization. **Hassan Rauf Chaudhry:** Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Irfan Kazi:** Writing – original draft, Validation, Project administration, Methodology, Conceptualization. **Muhammad Umar:** Writing – original draft, Supervision, Methodology, Conceptualization.

Appendix

Table A1
List of countries.

Albania	Estonia	Latvia	Poland	Sri Lanka
Armenia	Greece	Lebanon	Qatar	Syrian Arab Republic
Bahrain	India	Lithuania	Romania	Thailand
Bangladesh	Indonesia	Malaysia	Russian Federation	United Arab Emirates
Belarus	Israel	Moldova	Saudi Arabia	Uzbekistan
Bhutan	Jordan	Myanmar	Serbia	Vietnam
Bosnia and Herzegovina	Kazakhstan	Nepal	Singapore	Yemen, Rep.
China	Kuwait	Oman	Slovak Republic	–
Croatia	Lao PDR	Pakistan	Slovenia	–

Table A2
Detailed description of variables.

Variable Name	Description
LPI	Our study utilizes the Logistics Performance Index (LPI) as a key variable. The LPI is an aggregate measure designed to assess a country's logistics effectiveness, capturing various elements crucial to trade. These include the efficiency of customs clearance, the quality of infrastructure related to trade and transport, the ease of arranging shipments at competitive prices, the quality of logistics services, and the ability to track and trace consignments. Additionally, the index considers how frequently shipments reach their destinations on time. The LPI ranges from 1 to 5, where higher values signify better logistics performance. The data for this index are derived from surveys conducted by the World Bank in collaboration with academic institutions, international bodies, and private-sector participants in global logistics. Each survey collects feedback on key logistics performance areas from freight forwarders and logistics professionals, covering major import and export markets and regional neighbors for landlocked countries. The final score is calculated by averaging the results across the various dimensions, using statistical methods to ensure accuracy. More details on the survey and index methodology can be found in the World Bank's publication "Connecting to Compete 2010: Trade Logistics in the Global Economy (2010)"

(*continued on next page*)

Table A2 (*continued*)

Variable Name	Description
EFP	In our study, the Ecological Footprint (EFP) serves as a proxy variable for assessing environmental impact. The EFP quantifies the amount of biologically productive land and water required by an individual, population, or activity to sustain its resource consumption and to manage the waste it produces. This measurement takes into account current technologies and resource management practices. Typically expressed in global hectares, the Ecological Footprint captures the land or sea areas needed from around the globe to support a given level of consumption. While the term generally refers to the footprint related to consumption, it can also apply to broader activities. We use "Ecological Footprint" (EFP) to emphasize this measure throughout our study for clarity and consistency.
EXP	The variable EXP in our study acts as a proxy for the exports of goods and services. This measure represents the total value of a country's goods and services to the global market. It encompasses merchandise, freight, insurance, transportation, travel, royalties, license fees, and various services such as communication, construction, financial, information, business, personal, and government-related services. Employee compensation, investment income, and transfer payments are not included. The data for EXP are adjusted to constant 2015 prices and are expressed in U.S. dollars to account for inflation and ensure comparability over time.
IMP	Similarly, the variable IMP in our study represents the imports of goods and services. This measure captures the total value of goods and market services a country receives from other nations. It includes items such as merchandise, freight, insurance, transport, travel, royalties, license fees, and a range of services, including communication, construction, financial, information, business, personal, and government-related services. Excluded from this calculation are compensation of employees, investment income, and transfer payments. The data are presented in constant 2015 prices, expressed in U.S. dollars, to allow for accurate comparison across time periods.
GDP	GDP in our study represents the gross domestic product at purchaser's prices, capturing the total gross value added by all resident producers in the economy, along with product taxes and minus any subsidies that are not part of the product value. The calculation does not account for the depreciation of physical assets or the depletion and degradation of natural resources. GDP data are reported in constant 2015 U.S. dollars to ensure consistency over time, with conversions from domestic currencies using official exchange rates from 2015. In cases where official exchange rates do not accurately reflect the actual rates used in foreign exchange transactions, alternative conversion factors are applied.
Adj.NNI	Finally, the variable ADJ.NNI serves as a proxy for adjusted net national income. This measure is derived by taking the gross national income (GNI) and subtracting the consumption of fixed capital and the depletion of natural resources. It provides a more accurate reflection of a country's sustainable income by accounting for the depreciation of assets and the loss of natural resources.

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