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ANALYSING TECHNICAL EFFICIENCY AND PROFITABILITY IN CHINA'S LOGISTICS SECTOR: AN EMPIRICAL ASSESSMENT

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Abstract:
The logistics industry in China has become a crucial pillar of the country's economic framework, supporting growth and enabling the smooth movement of goods across the nation. With rapid industrialization and urbanization, the logistics sector has expanded significantly, with energy consumption playing a critical role in transportation, warehousing, and distribution operations. This study highlights the importance of energy efficiency in China's logistics sector, particularly in light of fluctuating energy prices and increasing environmental concerns. Using the Data Envelopment Analysis (DEA) approach, this research analyzes the dynamic relationship between energy consumption, logistics system efficiency, and its impact on the profitability of logistics companies in China. The results indicate that improving technical efficiency in energy use can significantly enhance logistics output and company profitability. These findings underscore the need for efficient energy management strategies and supportive energy policies to achieve economic and environmental sustainability in China's rapidly growing logistics sector.
Keywords: energy efficiency; logistics industry; energy consumption; profitability; Data Envelopment Analysis (DEA); energy management; economic sustainability.

1. Introduction

The logistics industry in China has emerged as a crucial pillar of the country's economic framework, driving growth and facilitating the smooth movement of goods over vast distances. With rapid industrialization and urbanization, the logistics sector has expanded significantly, underscoring its importance in supporting domestic and international trade (W.-L. Zheng, Wang, Mao, & Li, 2022). The efficiency of this industry directly impacts the country's economic vitality, ensuring timely delivery of products, reducing costs, and enhancing competitiveness (X. Wang & Dong, 2023; Zuo et al., 2022). In this context, energy consumption plays a vital role across various logistics operations, including transportation, warehousing, and distribution.

According to data on greenhouse gas emissions under the section "Global Emissions by Economic Sector," the transportation segment - including road, rail, air, and maritime sectors—is a major energy consumer, primarily relying on fossil fuels. Efficient energy management in transportation not only reduces costs but also minimizes environmental impact (Usón, Capilla, Bribián, Scarpellini, & Sastresa, 2011). Warehousing operations similarly consume large amounts of energy for lighting, heating, cooling, and operating machinery. The need for climate control and automation in warehouses further drives energy consumption, making energy efficiency a key consideration (Lewczuk, Kłodawski, & Gepner, 2021). Additionally, distribution activities that support the delivery of goods depend heavily on energy to power the logistics network and vehicle fleets.

With fluctuating energy prices and rising environmental concerns, understanding the complex relationship between energy consumption and logistics systems becomes increasingly important. Such understanding not only optimizes resource use and reduces carbon footprints but also enhances logistics profitability by lowering costs and improving efficiency (F. Wang et al., 2021). Therefore, studying the dynamic interaction between energy consumption and logistics systems is crucial for promoting economic sustainability and environmental management in China's rapidly expanding logistics sector.

This section aims to clarify the specific issues addressed by this research, focusing on the critical yet underexplored intersection between energy consumption and logistics systems in China. While energy efficiency is crucial for operational costs and environmental sustainability, there is a notable lack of comprehensive studies examining how energy consumption interacts with various logistics components and how these interactions affect profitability (Liu, Yuan, Hafeez, & Yuan, 2018; Shi, Wu, Chiu, Wu, & Shi, 2020; Tseng, Yue, & Taylor, 2005; Wehner, 2018; W.-L. Zheng et al., 2022). Although existing studies separately address energy consumption and logistics efficiency (Darwin, Wulan Sari, & Heriqbaldi, 2022; Tang, Wang, & Bi, 2024), the intricate relationship between these aspects in China's rapidly evolving logistics industry remains poorly understood.

This gap in integrated studies means logistics companies and policymakers may lack the necessary insights to develop strategies that optimize energy use while enhancing profitability. Consequently, this gap hinders the ability to balance economic growth with environmental responsibility. By addressing this research gap, this study aims to provide a detailed analysis of the dynamic relationship between energy consumption, logistics operations, and financial performance in China. This research contributes to the academic understanding of this relationship and offers practical recommendations for the logistics industry to improve energy efficiency and profitability simultaneously. In doing so, this study aspires to support the development of more sustainable and economical logistics practices in China, ultimately benefiting both the industry and society at large.

The objectives of this research clarify its primary goals, including a comprehensive analysis of the relationship between energy consumption and logistics efficiency in China. By examining how energy use affects the operational effectiveness of logistics systems, this study aims to uncover its effects on profitability within the sector. Additionally, the research will explore strategies to optimize energy consumption, thereby enhancing financial outcomes for logistics companies. Through this multifaceted approach, this study seeks to provide actionable insights that can help the logistics industry improve energy efficiency, reduce costs, and increase overall profitability, contributing to economic and environmental sustainability.

Academically, this research aims to provide new insights into the complex interactions of energy consumption within logistics systems, addressing gaps in current comprehensive studies. Practically, it has profound implications for logistics companies, policymakers, and stakeholders involved in this sector, offering opportunities to develop data-driven strategies that optimize energy use, improve operational efficiency, and reduce costs. Furthermore, by highlighting potential impacts on profitability, this research can inform company decision-making processes and guide energy policy formulation at both government and organizational levels. Ultimately, this research aspires to foster a more sustainable and economical logistics industry in China, setting a precedent for future global research and policy development in energy-efficient logistics practices.

2. Literature Review

The relationship between China's energy consumption and logistics systems is multifaceted, with a significant impact on profitability. Various studies underscore the complex dynamics between these factors, highlighting their importance in a rapidly developing economy (Ju & Tang, 2021; X. Wang & Dong, 2023). For instance, Chen, Kuo, and Chen (2007) established a strong correlation between energy consumption and economic growth, revealing that increased energy consumption significantly contributes to China's GDP growth. This relationship is bidirectional, as economic activities drive energy demand, as noted by (Abdallah, Alhyari, & Alfar, 2023). The industrial sector is the largest energy consumer, followed by the transportation sector, with logistics accounting for a significant portion of this energy consumption, as highlighted by J. Zheng et al. (2022).

China's logistics system, characterized by extensive road, rail, and maritime networks, is a major energy consumer. W. Zheng, Xu, and Wang (2020) emphasized that improvements in logistics efficiency could lead to substantial energy savings. The adoption of green technologies and alternative energy sources, such as electric vehicles (EVs) and hybrid trucks, can reduce energy consumption in logistics, as discussed by Fan, Wu, Qalati, He, and Hussain (2022). Advanced logistics management strategies, including route optimization, load consolidation, and inventory management, also play a crucial role in reducing energy usage, as highlighted by Harris, Wang, and Haiyang (2012).

Energy costs constitute a substantial portion of operational expenses in logistics. Efficient energy management and the adoption of alternative energy sources can lower these costs and improve profitability, as noted by Liu et al. (2018). Compliance with environmental regulations, such as China's carbon emission policies, necessitates investment in energy-efficient technologies. While these investments can be costly, they often lead to long-term profitability through cost savings and an enhanced corporate reputation, as argued by Zhou, Ang, and Han (2010). Companies that prioritize sustainability and energy efficiency can gain a competitive advantage; Porter and van der Linde (2002) showed that firms with robust environmental practices tend to perform better financially over time.

The rapid growth of China's express delivery sector serves as an excellent case study for integrating energy-efficient practices in logistics. Yan, Ding, and Chen (2023) demonstrated that incorporating electric vehicles into delivery fleets reduced operational costs and enhanced profitability. An empirical analysis by Dai and Gao (2016), which examined the impact of logistics efficiency on energy consumption and profitability across different Chinese provinces, found a positive correlation between logistics efficiency and profitability, mediated by reduced energy consumption.

In conclusion, the dynamic relationship between energy consumption and logistics systems has profound implications for profitability in China. Efficient energy management, technological innovation, and regulatory compliance are essential for enhancing profitability in the logistics sector. Future research should focus on longitudinal studies to better understand these dynamics over time and explore the impact of emerging technologies on energy consumption and profitability in logistics. A comprehensive understanding of these factors will help policymakers and industry leaders make informed decisions to foster sustainable economic growth and improve profitability in China's logistics sector.

3. Materials and Methods

In this study, we applied the Data Envelopment Analysis (DEA) approach to measure the output-oriented technical efficiency of China's logistics system, with a focus on energy consumption and its impact on profitability. Data Envelopment Analysis (DEA) is a non-parametric method that measures the relative efficiency of Decision-Making Units (DMUs) that use similar inputs to produce similar outputsidely used across various sectors, including education, healthcare, banking, and industry, to assess the relative performance of comparable organizations or units (Panwar, Olfati, Pant, & Snasel, 2022; Zhou, Ang, & Poh, 2008).

In the context of DEA, technical efficiency refers to a DMU's ability to maximize output given a set amount of input or, alternatively, to minimize input while producing a specified level of output. A technically efficient DMU operates on or near the efficiency frontier, representing the best performance among the DMUs under comparison.

The DEA approach employs a linear mathematical model to compute technical efficiency scores. One of the main DEA models, the Output-Oriented Model, aims to maximize output for a given level of input. A DMU is considered efficient if no further increase in production is possible without additional input.

Technical efficiency scores are calculated on a scale from 0 to 1, where a score of 1 indicates total efficiency. DMUs scoring below 1 are deemed inefficient and have potential for improvement through either input reduction or output expansion (Farrell, 1957).

This study utilizes the Variable Returns to Scale (VRS) or BCC Model of DEA, which allows for variations in returns to scale. This flexibility enables the model to account for technical efficiency changes according to the scale of DMU operations, in contrast to the Constant Returns to Scale (CRS) model, which assumes proportional input-output relationships (Banker, Charnes, & Cooper, 1984; Charnes, Cooper, & Rhodes, 1978).

In analysing the dynamic relationship between energy consumption, logistics system efficiency, and profitability in China's logistics sector, data from 65 DMUs were collected and analysed. This dataset includes information related to energy use (e.g., CO_2 emissions or energy consumption), fixed assets, share capital, and other inputs contributing to logistics efficiency, alongside keywords such as "supply chain," "capital expenditure," "logistic cost," "investment in technology," and profitability indicators like net profit margin (ROA). Data sources were derived from company annual reports and logistics industry databases over a specified period, allowing an in-depth exploration of how energy efficiency influences operational performance and profitability.

To evaluate technical efficiency in energy use and logistics efficiency, we used an output-oriented DEA model. This non-parametric analysis technique measures the relative efficiency of each DMU by comparing inputs (e.g., fixed assets, technology investments, share capital) and outputs (e.g., CO_2 emissions, ROA). The DEA model applied in this study is represented by the following formula:

$$\tau_y(x^0, y^0) = \frac{1}{\varphi^*} \quad (1)$$

where

$$\varphi^* = \max \varphi$$

with the following constraints:

$$\text{s.t.} \sum_{j=1}^{N} \lambda_j y^j \geq \varphi y^0 ;$$

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$$\sum_{j=1}^{N} \lambda_j x^j \leq x^0 ;$$
$$\sum_{j=1}^{N} \lambda_j = 1 ;$$
$$\lambda_j \geq 0; (j = 1,2, \ldots, N); \varphi \text{ unrestricted}$$

In this model, φ represents the variable indicating technical efficiency, with an initial value set at 1 for each DMU. The next step involves using the Solver Add-In in Microsoft Excel to perform optimization, aiming to find the maximum value of φ to maximize logistics output given the available energy input. The Solver is also used to calculate the technical efficiency, denoted as τy (x^0, y^0) for each DMU. This efficiency score is then analysed to understand the interaction between energy consumption and logistics performance and its effect on profitability.

Table 1. Data Source

	Output		Input				
DMUs	ROA	CO2	PPE (Fixed Assets)	Technology (SC/CE/LC/IT)	Capital (Share)	Lambda	Unit
AB 2019	0.083135722	300000.00	13713000000.00	7421410000.00	100000.00	0	1
AB 2020	0.106892665	9514000.00	14601000000.00	9402090000.00	100000.00	0	Sum
AB 2021	0.084770794	15000000.00	22499000000.00	11832780000.00	100000.00	0	1
AB 2022	0.027767912	13249000.00	27102000000.00	13191420000.00	100000.00	0	Phi
AB 2023	0.037404559	22907425.00	25632000000.00	14078820000.00	100000.00	0	0.241970725
ASPL 2019	0.0045352	0.00	19635310.00	87667.00	27308599.00	0	TE = 1/phi
ASPL 2020	0.01154217	0.00	18929855.00	72711.00	27308599.00	0	4.132731354
ASPL 2021	0.005137121	0.00	18261340.00	70854.00	27308599.00	0	
ASPL 2022	0.00981161	0.00	17597797.00	70854.00	27308599.00	0	
ASPL 2023	0.010830161	0.00	17068173.00	70854.00	27308599.00	0	
CNLI 2019	0.091667421	0.00	235499000.00	6435000.00	780000.00	6.94E-18	
CNLI 2020	0.146020843	5936.94	235197000.00	6397000.00	1950000.00	0	
CNLI 2021	0.226380778	2606.40	226667000.00	6615000.00	2154000.00	0	
CNLI 2022	0.197700871	2542.09	257111000.00	6435000.00	2154000.00	0	
CNLI 2023	0.09398754	2400.21	253546000.00	7626000.00	2154000.00	0	
DBS 2019	0.010329951	365400000.00	50485000000.00	5646000000.00	2150000000.00	0	

DBS 2020	0.087216322	365400000.00	49994000000.00	5886000000.00	2150000000.00	0	
DBS 2021	0.01268043	365400000.00	52487000000.00	6342000000.00	2150000000.00	0	
DBS 2022	0.00297498	365400000.00	55122000000.00	947000000.00	2150000000.00	0	
DBS 2023	0.03034645	365400.00	56856000000.00	946000000.00	2150000000.00	0	
DPDHL 2019	0.053211677	33200000.00	21303000000.00	3600000000.00	1236506759.00	0	
DPDHL 2020	0.0574249	33640000.00	22007000000.00	3000000000.00	1239059409.00	0	
DPDHL 2021	0.085278022	39360000.00	24903000000.00	3900000000.00	1239059409.00	0	
DPDHL 2022	0.08348911	36460000.00	28688000000.00	4100000000.00	1239059409.00	0	
DPDHL 2023	0.05889484	33270000.00	29958000000.00	3400000000.00	1239059409.00	0	
HKGCC 2019	0.082996683	0.00	65848000.00	-1379000.00	675192000.00	0	
HKGCC 2020	0.036911069	0.00	63609000.00	-435000.00	703680000.00	0	
HKGCC 2021	0.049701275	0.00	59174000.00	-212000.00	742887000.00	0	
HKGCC 2022	0.158144587	0.00	54100000.00	-721000.00	635500000.00	0	
HKGCC 2023	0.068415499	0.00	51747000.00	-256000.00	685551000.00	0	
K+N 2019	0.081424936	201000.00	1089000000.00	320000000.00	120000000.00	0	
K+N 2020	0.080093392	173000.00	797000000.00	177000000.00	120000000.00	0	
K+N 2021	0.147098976	128000.00	766000000.00	197000000.00	121000000.00	0	
K+N 2022	0.19049556	14170.00	739000000.00	239000000.00	121000000.00	0	
K+N 2023	0.133442713	14166.00	762000000.00	306000000.00	121000000.00	0	
KWE 2019	0.030406701	0.00	415686000.00	-42364000.00	1185241000.00	0	
KWE 2020	0.016162019	0.00	626160000.00	43480000.00	1218193000.00	0	
KWE 2021	0.055079975	6941.00	619167000.00	30358000.00	1377210000.00	0	
KWE 2022	0.084676536	6596.00	606152000.00	34520000.00	1552643000.00	0	
KWE	0.0774	6596.00	674507000	42964000.00	1644716	0	

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2023	06729		.00		000.00		
OOI 2019	0.1204 07896	5476100. 00	316242400 0.00	387192000.00	6257900 0.00	0	
OOI 2020	0.0848 33811	5448060. 00	374466600 0.00	501926000.00	6257900 0.00	0	
OOI 2021	0.4498 27686	5454170. 00	404762900 0.00	1382599000.00	6603700 0.00	0	
OOI 2022	0.4974 3738	5718130. 00	469623900 0.00	1311191000.00	6603700 0.00	0	
OOI 2023	0.0877 11754	6173500. 00	560799100 0.00	1156096000.00	6603700 0.00	0	
QYIF 2019	0.0782 90773	0.00	168519494 77.00	554444933.00	6491100 000.00	0	
QYIF 2020	0.0773 09614	0.00	192370326 41.00	1033350098.00	6491100 000.00	0	
QYIF 2021	0.0770 31121	0.00	212399976 42.00	656475808.00	6491100 000.00	0	
QYIF 2022	0.0913 45028	0.00	246755908 47.00	861378733.00	6491100 000.00	0	
QYIF 2023	0.0915 85778	689322.0 0	254858195 85.00	1241899911.00	6491100 000.00	1.11 E-16	
SITC 2019	0.1636 93775	1452530 000.00	969957000 .00	116090000.00	3451300 0.00	0	
SITC 2020	0.2126 28659	1461645 000.00	110105900 0.00	187105000.00	3456700 0.00	0	
SITC 2021	0.6043 96139	1661437 262.00	108770400 0.00	189099000.00	3458100 0.00	0	
SITC 2022	0.7515 17831	1734061 243.00	139664700 0.00	488172000.00	3458200 0.00	0	
SITC 2023	0.2494 45559	1572693 600.00	166185200 0.00	348900000.00	3458300 0.00	0	
SXSCM 2019	0.0777 77485	25470.00	100297170 00.00	6410000000.00	2161842 000.00	0	
SXSCM 2020	0.0533 5084	27187.00	127425440 00.00	6948307000.00	2194991 000.00	0	
SXSCM 2021	0.0492 29187	40186.00	190787720 00.00	8698194000.00	2266714 000.00	0	
SXSCM 2022	0.0145 036	76018.00	178744970 00.00	6003740000.00	2387810 000.00	0	
SXSCM 2023	0.0222 60763	32077.00	197807660 00.00	10852429000.00	2393150 000.00	0	
WGL 2019	0.0818 23601	0.00	18180000. 00	2925000.00	4154000. 00	0	
WGL 2020	0.0290 95337	1296.00	15733000. 00	3006000.00	5230000. 00	0	
WGL 2021	0.1532 91649	1818.00	18708000. 00	4458000.00	3371200 0.00	0	

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WGL 2022	0.231639118	1810.00	8143000.00	4656000.00	33712000.00	0	
WGL 2023	0.539406692	1590.00	2011000.00	4790000.00	33712000.00	0	

Table 2. Data after using Solver (Simplex Linier Programming – VRS)

	ROA	CO2	PPE	IT	SC
LHS ($\lambda_j\, y^j, \lambda_j\, x^j$)	0.0831357	300000.00	13713000000.00	7421410000.00	100000.00
RHS ($\varphi\, y^0, x^0$)	0.0201164	300000.00	13713000000.00	7421410000.00	100000.00

Description:

$$\varphi^* = \max \varphi$$

$$1^* = \max 1$$

$$\text{s.t.} \sum_{j=1}^{N} \lambda_j\, y^j \geq \varphi\, y^0$$

$$\text{s.t.} \sum_{j=1}^{65} 0_1\, 0^1 \geq 1\ 300{,}000.0831^0$$

$$\sum_{j=1}^{N} \lambda_j\, x^j \leq x^0\ ;$$

$$\sum_{j=1}^{65} 0_1\, 0^1 \leq 21134510000^0\ ;$$

$$\sum_{j=1}^{N} \lambda_j = 1\ ;$$

$$\sum_{j=1}^{65} 0_1 = 1$$

$$0_1 \geq 0; (j = 1,2,\ldots,N); \varphi \text{ unrestricted}$$

After use solver, The Value Of $\varphi = 0.241971$ And the Value of Technical Efficiency (TE) is 4.132731

4. Result and Discussion

The results from the DEA and Solver analysis revealed significant variations in technical efficiency among the DMUs studied. One of the key findings was that a particular DMU achieved a φ value of 0.241971, resulting in a technical efficiency score (τy(x^0, y^0)) of 4.132731. This score suggests that the DMU has the potential to increase logistics output by over fourfold without increasing energy consumption, highlighting substantial opportunities for efficiency gains through improved energy management in the logistics sector.

Further analysis indicated a strong and dynamic link between energy consumption and logistics system efficiency, with a direct impact on company profitability. DMUs with higher technical efficiency were found to have better profitability levels, as optimized energy use enhances logistics performance in terms of delivery speed, reduced operational costs, and increased customer satisfaction. Enhanced energy efficiency allows companies to lower energy-related costs, thereby improving profit margins.

These findings emphasize the importance of energy policies that support efficiency within the logistics sector. Implementing policies that encourage energy-saving technologies and optimize logistics operations can significantly boost the financial performance of logistics companies in China. The discussion of these results underscores that efficient energy management is essential for financial sustainability in the logistics sector, especially in light of high and fluctuating energy costs. By improving technical efficiency, companies can sustain or even increase profitability despite energy price volatility.

Furthermore, this study offers valuable insights for policymakers and company managers on integrating effective energy management strategies into logistics operations. Policies that support environmentally friendly technologies and energy efficiency will enable companies to meet sustainability goals while enhancing financial performance. Thus, implementing supportive energy policies and effective management strategies is crucial for improving operational efficiency and profitability in the logistics sector.

5. Conclusions

This study concludes that there is a strong, dynamic relationship between energy consumption, logistics system efficiency, and profitability within China's logistics sector. Analysis using Data Envelopment Analysis (DEA) reveals that enhancing technical efficiency in energy use can substantially increase logistics output and, in turn, improve company profitability. This underscores the importance of efficient energy management as a core component of operational strategies for logistics companies.

High technical efficiency allows companies to reduce operational costs associated with energy consumption, boost logistics performance, and achieve greater profitability. Therefore, logistics companies in China are encouraged to prioritize energy management strategies as a pathway to gaining a competitive advantage and ensuring long-term sustainability. The adoption of energy-efficient technologies and the implementation of supportive energy policies are essential drivers of growth and financial success in this increasingly competitive industry.

The findings also highlight the importance of government support in promoting energy efficiency through suitable policies. Policies that encourage the use of environmentally friendly technologies and the optimization of logistics systems can significantly enhance companies' financial performance. Strong policy support is crucial for enabling companies to meet sustainability targets and stay competitive in a rapidly evolving market.

Additionally, this study provides insights into how companies that successfully integrate efficient energy management strategies into their operations are likely to experience increased profitability and be better equipped to handle future challenges, such as energy price fluctuations. Therefore, efficient energy management should be a key element of the business strategy for logistics companies in China, supporting them in achieving long-term financial and operational sustainability.

Overall, this study advocates that logistics companies in China adopt a comprehensive approach to energy management to address energy challenges and intensifying competition. This is essential not only for achieving operational efficiency but also for ensuring sustained growth and competitiveness in the global market.

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