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Comparative Analysis of Port Efficiency in ECOWAS: Case Studies of Major Ports

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Abstract: The efficiency of ports in the Economic Community of West African States (ECOWAS) plays a crucial role in enhancing regional trade corridors and economic integration. However, persistent infrastructural limitations, congestion, and inefficiencies in port operations have hampered their ability to compete globally. This study conducts a comparative efficiency analysis of four major ECOWAS ports—Abidjan, Tema, Lagos, and Lomé—using Data Envelopment Analysis (DEA) to measure technical and scale efficiency from 2011 to 2024. Additionally, a SWOT analysis is employed to assess the strengths, weaknesses, opportunities, and threats affecting these ports. The analysis reveals that the Port of Lomé demonstrates the highest efficiency, consistently achieving Charnes, Cooper, and Rhodes (CCR) and Banker, Charnes, and Cooper (BCC) efficiency scores of 1.0 by 2024. This superior performance is attributed to its strategic role as a transshipment hub, extensive infrastructure investments, and operational improvements. The Port of Lagos, despite maintaining high technical efficiency (BCC = 1.0), experiences fluctuations in CCR scale efficiency due to congestion and operational constraints. The Port of Abidjan shows steady improvement, benefiting from infrastructure expansion, but remains constrained by its reliance on the Vridi Canal. In contrast, the Port of Tema ranks the lowest in efficiency, facing persistent scale inefficiencies and infrastructure limitations that hinder its operational performance. This study highlights the crucial role of infrastructure investment, digitalization, and trade facilitation reforms in improving port efficiency. Policy recommendations include automation of port operations, expansion of multimodal transport linkages, and stronger public-private partnerships (PPPs) to optimize performance and enhance regional connectivity. By contributing a longitudinal DEA-based efficiency assessment, this research adds to the existing literature by providing empirical evidence on efficiency trends in ECOWAS ports and offering strategic insights for policymakers, port authorities, and trade stakeholders.

Keywords: ECOWAS ports; Efficiency; DEA; CCR model; BCC model; SWOT analysis; Trade integration; Infrastructure; Digitalization; Sustainability.

1. Introduction

The Economic Community of West African States (ECOWAS) plays a crucial role in fostering regional economic integration and trade cooperation among its 15 member states. It gives the region's reliance on maritime trade, the efficiency of ports is a factor in reducing logistics costs, improving trade flows, and strengthening regional competitiveness. The ports of Abidjan (Côte d'Ivoire), Lagos (Nigeria), Tema (Ghana), and Lomé (Togo) serve as major trade hubs, facilitating access to international markets for coastal and landlocked countries such as Burkina Faso, Mali, and Niger as shown in the Fig. 1 [1].

Despite their strategic importance, these ports face significant operational and structural challenges. Fontagné et al. reported issues such as congestion, cargo processing delays, limited infrastructure investment, and weak multimodal connectivity, all of which hinder trade efficiency. Vessels spend an average of 1.8 days in ports, and poor infrastructure accounts for more than 40% of predicted transport costs [2]. Strengthening port, road, and rail integration could boost African exports by 11.5% and GDP by 2%, emphasizing the need for strategic investment [3, 4, 5]. While some ports, such as Lomé, have improved their efficiency through infrastructure modernization and private sector involvement [6]. In contrast, several ports in Sub-Saharan Africa face severe administrative bottlenecks and inefficient logistics management, including Douala (Cameroon), Lagos (Nigeria), Dar es Salaam (Tanzania), Mombasa (Kenya), and the Abidjan-Lagos corridor. These ports suffer from congestion, slow customs clearance, corruption, poor GPS tracking, and weak inland connectivity due to inadequate road and rail infrastructure [7].

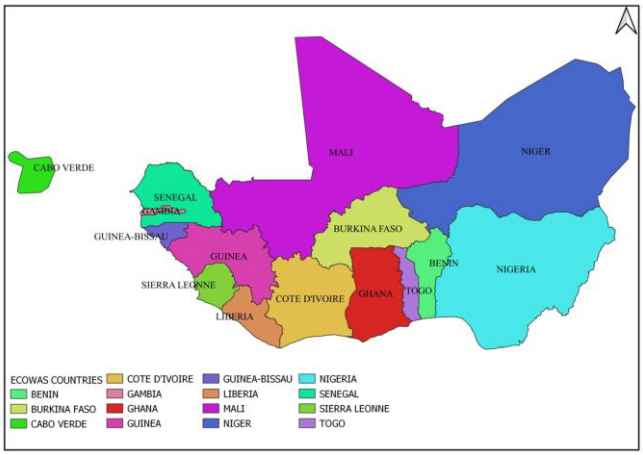

Figure 1. Countries in the ECOWAS region [8]

According to Ouedraogo (2024), the Port of Lomé has leveraged deep-water access and modernized facilities, positioning itself as a major hub in West Africa, while other

regional ports face challenges such as congestion and inefficiencies [9]. The disparity in performance among ECOWAS ports necessitates a comparative efficiency assessment to identify determinants of efficiency and propose strategies for improvement. Another study by Pálsson et al. and Konstantinus et. al demonstrated ports in West and Central Africa face significant efficiency challenges, leading to high costs for shippers and reduced regional competitiveness [10, 11]. On the other hand, Danladi et al. emphasized the need for port management reforms and benchmarking to enhance port productivity and lower maritime transport costs [12].

Table 1. Annual Container Throughput and Major Operators at Key West African Ports (2018–2024)

Year	Port name (country)	Annual Throughput (1000 Teu) *	Major operators	Annual vessel capacity (million Teu)	Source
	Abidjan (Cote d'ivoire)				[13]
2024		1 600 000	MSC, AT, AGL, CIT	2,5	
2023		1 238 195	MSC, AT, AGL, CIT	2,5	
2022		840926	BAL, AT, CIT	2,5	
2021		787314	BAL, AT,	1,5	
2020		760149	BAL, AT,	1	
2019		730827	BAL, AT,	1,5	
2018		674624	BAL, AT,	1	
	Lome (Togo)				[14]
2024			CMA, CGM, CMPort, MSC, BAL		
2023		1900000	CMPort, MSC, BAL	2,2	
2022		1952879	CMPort, MSC, BAL	2,2	
2021		1962304	CMPort, BAL, TIL	2,2	
2020		1725270	CMPort, BAL	2,2	
2019		1500611	CMPort, BAL	2,2	
2018		1395733	CMPort, BAL	2,2	
	Tema (Ghana)				[15]
2024		1900000	GPHA, MPS, APTM, AGL	3,5	
2023		1190695	GPHA, MPS, APTM, AGL	3,5	
2022		1205546	GPHA, MPS, APTM, AGL	2,5	
2021		1519276	GPHA, MPS, APMT, AGL	2,5	
2020		1248726	MSC + APMT + GPHA	2	
2019		1000926	GPHA, MPS, APMT, AGL	1,5	
2018		1000967	GPHA, MPS, APMT, AGL	1	
	Lagos (Nigeria)				[16]
2024			BAL, APMT, ENL	3,7	
2023		1566162	BAL, APMT, ENL	1.5	
2022		1566109	BAL, APMT, ENL	1.5	
2021		20298223	BAL, APMT, ENL	3.5	
2020		1073807	BAL, APMT, ENL	1	
2019		1032253	BAL, APMT, ENL	1	
2018		1000967	BAL, APMT, ENL	1	

Table 1 demonstrates the data on container throughput in West African ports from 2018 to 2024 reveals a steady growth trend, with Abidjan and Tema more than doubling their capacities, reaching 1.6 million TEUs and 1.9 million TEUs, respectively, by 2024. Lomé has remained a consistent high performer, handling around 2 million TEUs since 2019, while Lagos has shown fluctuations, peaking unexpectedly in 2021. The increasing presence of global operators like MSC, CMA CGM, and APMT has driven port efficiency and capacity expansion, with Tema and Lagos leading in annual vessel capacity at 3.5 million TEUs and 3.7 million TEUs, respectively. These trends highlight West Africa's growing role in global trade, supported by strategic infrastructure investments and rising cargo demand.

Port efficiency is typically assessed using both quantitative and qualitative indicators [17]. Boakye et al. explained that port efficiency is traditionally assessed using indicators such as berth occupancy, revenue per ton of cargo, and vessel turnaround time. However, these traditional metrics do not fully capture how effectively resources are utilized [18]. To address this limitation, Data Envelopment Analysis (DEA) is widely applied to benchmark efficiency across multiple decision-making units (DMUs) [19, 20, 21]. DEA evaluates how ports convert inputs (e.g., terminal area, number of cranes, berth length) into outputs (e.g., cargo throughput, number of vessel calls, processing speed) [22]. Although DEA is effective in identifying efficiency rankings, it does not explain the underlying causes of inefficiencies. To complement this quantitative approach, SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats) is integrated to provide strategic insights into factors affecting port competitiveness [23]. The combination of DEA and SWOT analysis enables a comprehensive evaluation of port efficiency by incorporating both empirical performance metrics and qualitative strategic assessments [24, 25]. The case study aims to assess and compare the efficiency of the

ports of Abidjan, Tema, Lagos, and Lomé through the application of DEA and SWOT analysis. Specifically, the objectives are to (i) measure technical and scale efficiency using the CCR and BCC DEA models, (ii) analyze efficiency trends over the period 2011–2024, (iii) identify operational and strategic factors influencing port performance, and (iv) propose recommendations to enhance regional trade integration and logistics performance. By integrating quantitative DEA-based efficiency assessment with qualitative SWOT-based strategic evaluation, this study provides a holistic perspective on ECOWAS port performance. The findings will offer valuable insights for policymakers, port authorities, and trade stakeholders in developing strategies to optimize port infrastructure and enhance trade efficiency.

This study is structured into six sections, Section provides introduction of the study, Section 2 presents the literature review, summarizing prior research on port efficiency, efficiency measurement methodologies, and comparative port performance studies in Africa. Section 3 details the methodology, explaining the DEA models applied, selected input-output variables, and the integration of SWOT analysis. Section 4 outlines the results and analysis, highlighting efficiency trends among the selected ports. Section 5 discusses the findings, interprets efficiency variations, and provides strategic recommendations. Finally, Section 6 concludes the study by summarizing insights and suggesting areas for future research and policy development.

2. Literature Review

2.1. Theoretical Background

Port efficiency has emerged as a crucial component in understanding the dynamics of global trade and regional economic integration, particularly in developing economies. Theoretical models like production theory, which evaluates the transformation of inputs (e.g., labor, infrastructure, capital) into outputs (e.g., cargo throughput, service quality), underpin the study of port efficiency. Data Envelopment Analysis (DEA) has been extensively employed as a non-parametric method in operational research to measure the relative efficiency of decision-making units such as ports [26]. DEA models help determine technical and scale efficiency, offering nuanced insights into how ports utilize their resources to maximize performance [27]. Two principal DEA models are utilized in port studies: the CCR model, which assesses efficiency under constant returns to scale (CRS), and the BCC model, which measures efficiency under variable returns to scale (VRS). The CCR model is essential for understanding a port's ability to achieve optimal output regardless of size, while the BCC model adjusts for scale, providing a clearer picture of how port operations might be influenced by their scope [28]. These methodologies are invaluable for policymakers and port authorities aiming to identify performance gaps and prioritize investments.

2.2. Importance of Port Efficiency in Economic Development

The significance of port efficiency extends beyond simple operational metrics; it is a pivotal determinant of economic performance. Ports serve as essential trade gateways, facilitating the movement of goods and contributing to the economic growth of both coastal and landlocked countries. In the ECOWAS region, port operations play a fundamental role in supporting trade activities, providing a crucial link between local markets and international trade routes [29]. Efficient ports reduce logistics costs, enhance the competitiveness of exports, and attract foreign investment by ensuring reliable and timely cargo handling [30].

Past studies have underscored those ports operating at higher efficiency levels tend to drive regional development more effectively. For instance, Baafi et al. founded a significant correlation between port efficiency and economic growth in Africa, indicating that regions with better-performing ports enjoy enhanced trade volumes and economic resilience [31]. Ports that are well-managed contribute to job creation, income generation, and increased government revenue through trade taxes and fees, forming an integral part of national and regional economic strategies [32]. Moreover, the ripple effects of efficient port operations extend to landlocked countries within ECOWAS [33]. These nations rely on regional ports for access to international markets. Port inefficiencies, such as delays, high handling costs, and suboptimal infrastructure, disproportionately impact landlocked countries by increasing their trade costs and reducing their global competitiveness [34]. Therefore, improving port efficiency is not only a national concern but a regional imperative for ensuring equitable economic benefits.

2.3. Previous Comparative Studies on Port Efficiency

Research around port efficiency in the ECOWAS region has been progressively expanding, albeit with notable limitations. Miezah et al. conducted an in-depth analysis using DEA to evaluate the efficiency of gateway ports for landlocked West African countries [35]. This study highlighted the significant role that technical efficiency plays in determining a port's suitability for handling trade from non-coastal nations. Similarly, Abbes et al. carried out a comparative study to assess the competitiveness of West African container ports, employing DEA models to illustrate performance disparities and the influence of port-specific factors such as infrastructure and management practices [36]. Sakyi et al. focused on service quality in ECOWAS ports, revealing critical issues such as inconsistent service delivery, which undermines the efficiency and reliability of port operations. This research offered valuable insights into non-operational factors influencing port performance, including customer satisfaction and service consistency [37]. Another study by Chilaka, E. (2022) explored the development of river and deep-sea ports in Nigeria, using DEA models to underscore the strategic importance of diversified port types and their implications for overall port efficiency [38]. In contrast, study by Lisinge et al. introduced a unique perspective by examining the operational efficiency of West African ports within the context of the Belt and Road Initiative [39]. This study applied a super-efficiency DEA model to evaluate ports' performance under external investment pressures and international trade partnerships. Findings suggested that while some ports benefit from increased funding and modernization efforts, others struggle with structural inefficiencies that limit the impact of external support.

Comparative analyses in other African regions, such as Gamassa et al. worked on East African ports, provide useful parallels for understanding efficiency challenges in ECOWAS [40]. These studies show that regional disparities in port efficiency often stem from differences in governance,

infrastructure investment, and technology adoption [41]. The lessons learned from these comparative efforts emphasize the need for consistent policy frameworks and investments tailored to regional needs. Despite the wealth of literature on port efficiency, significant gaps remain, particularly in the context of comparative studies focused solely on the ECOWAS region. Many existing studies either lack comprehensive cross-regional analyses or are dated, failing to incorporate recent data and developments that impact current port operations [42]. Additionally, while DEA models are frequently employed, there is a need for studies that integrate advanced variations of these models to capture more intricate efficiency distinctions, such as scale versus technical efficiency [43]. Moreover, the literature often emphasizes quantitative analyses without sufficient qualitative insights into the strategic and operational challenges that ports face. SWOT analyses, which combine data-driven results with strategic considerations, are underrepresented in current research. This study aims to bridge these gaps by conducting a detailed comparative analysis of ECOWAS ports, integrating both DEA models and SWOT analyses to offer a holistic view of port efficiency and strategic positioning. By addressing these research gaps, this paper will contribute to the growing body of knowledge on port efficiency, providing updated empirical evidence and strategic insights that can guide policymakers, port authorities, and regional stakeholders in developing targeted solutions to enhance port operations and support regional trade growth.

3. Methodology

This study uses a mixed-methods approach, combining quantitative efficiency analysis via Data Envelopment Analysis (DEA) with qualitative strategic insights from SWOT analysis to evaluate four ECOWAS ports: Abidjan (Côte d'Ivoire), Tema (Ghana), Lagos (Nigeria), and Lomé (Togo) over a 13-year period (2011-2024). DEA models assess technical and scale efficiency, while SWOT analysis examines the strengths, weaknesses, opportunities, and threats associated with each port Fig.2 shows the geographic distribution of these ports and their trade corridors.

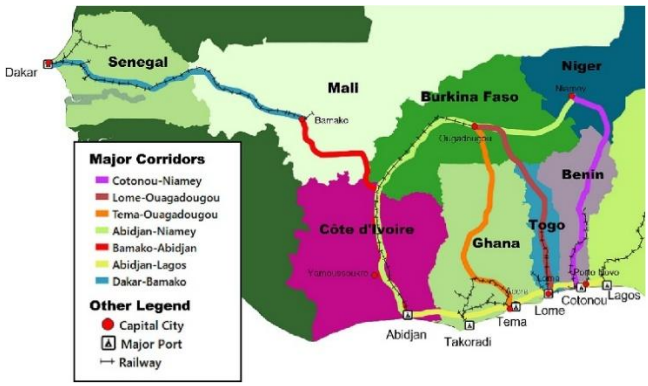

Figure 2. Study Area – ECOWAS Ports and Trade Corridor [44].

The selection of these four ports (See Table 2) as Decision-Making Units (DMUs) is based on several criteria, including their container handling capacity, significance in regional trade corridors, and the availability of reliable data for robust comparative assessment [45]. The data used in this study comes from official reports from port authorities, regional organizations, and international institutions. The main sources include management reports from the ports of Abidjan, Tema, Lagos, and Lomé, publications from ECOWAS and World Bank , UNCTAD, as well as databases from the World Bank and UNCTAD [46]. These sources provide detailed information on port infrastructure, logistics performance, and trade flows. Additionally, academic studies were reviewed to better understand infrastructure developments and port management strategies.

To assess port efficiency, Data Envelopment Analysis (DEA) has applied, a comparative analysis tool that measures the relative performance of ports based on their resource utilization and service output. The selected ports are treated as DMUs, as they share similar operational characteristics and compete for regional maritime trade. The table 2 below presents the selected ports.

Table 2. DEA Decision-Making Units (DMUs)

S/N	Country	Port Name
1	Côte d'Ivoire	Port of Abidjan
2	Ghana	Port of Tema
3	Nigeria	Port of Lagos
4	Togo	Port of Lomé

The study is based on four input variables and one output variable to measure port efficiency over the 15-year period (2011-2024). The input variables, reflecting port infrastructure and operational capacity, include terminal area, quay length, number of cranes, and number of berths. The output variable, which measures port productivity, is container throughput in TEUs. These variables were selected for their relevance in efficiency assessment and their availability in the analysed databases based on chosen variables as summarized in Table 3 [26].

Table 3. DEA inputs and output variables.

Inputs	Outputs
Terminal Area (ha)	Container throughput (TEU)
Quay length (m)	
Number of cranes	
Number of berths	

3.1. Data Analysis

In this study, Data Envelopment Analysis (DEA) is applied using two models: the CCR model and the BCC model. The CCR model assumes constant returns to scale and evaluates overall technical efficiency, meaning that ports are expected to operate at an optimal scale.

In contrast, the BCC model introduces VRS by adding a convexity constraint, which allows for the assessment of pure technical efficiency, distinguishing it from scale efficiency. [41]. Both models use a linear programming approach to determine the efficiency score θ of a port by comparing its inputs and outputs to those of other ports in the dataset [41]. The general DEA optimization model aims to maximize θ while ensuring that the weighted sum of inputs and outputs remains within defined constraints. The optimization equation can be expressed as:

$$\min\ \theta$$

Subject to:

$$\sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{io}, \quad \forall_i \qquad (1)$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{ro}, \quad \forall_r \ \ldots$$

$$\lambda_j \geq 0, \quad \forall_j$$

Where x_{ij} and y_{rj} represent the inputs and outputs of the ports, respectively. The variables λj are weighting coefficients, which are used to compare inefficient ports against the most efficient ones. The variable (θ)represents the efficiency score of each port, where a value of 1 indicates full efficiency, while values less than 1 indicate inefficiency [41].

The distinction between the CCR and BCC models lies in their treatment of scale efficiency. The CCR model assumes that efficiency is independent of port size, meaning that all ports should operate at an optimal scale. However, the BCC model introduces a convexity constraint:

$$\min \ \theta$$

Subject to:

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta x_{io}, \quad \forall_i$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{ro}, \quad \forall_r \ \ldots$$

$$\lambda_j \geq 0, \quad \forall_j$$

$$\sum_{j=1}^{n} \lambda_j = 1 \qquad (2)$$

Which ensures that ports are only compared to units of similar scale, making it possible to separate pure technical efficiency from scale efficiency.

Once efficiency scores are obtained, the CCR model provides Overall Efficiency (OE), while the BCC model yields Pure Technical Efficiency (PTE) [47]. Scale Efficiency (SE) is then calculated using the ratio:

$$SE = \frac{OE}{PTE} \qquad (3)$$

This ratio helps to determine whether inefficiencies in a port stem from managerial issues (low PTE) or suboptimal scale of operation (low SE). By applying both models, this study provides a comprehensive evaluation of port efficiency, identifying the extent to which inefficiencies are due to poor resource management or structural limitations within ECOWAS ports [47].

4. Results

The results reveal significant variations among the studied ports, with some ports demonstrating continuous efficiency improvements, while others show stagnation or fluctuating performance. To provide a clear overview, efficiency scores over the period have been identified for each port. These scores highlight performance gaps over the years and allow for an evaluation of efficiency trends over time. The efficiency scores for each port from 2011 to 2024 are summarized in Table 4, which outlines the yearly variations in BCC and CCR efficiency scores. A graphical representation of the efficiency trends is illustrated in Fig. 3 providing a visual depiction of efficiency changes across the study period.

Table 4. Efficiency scores derived from DEA methods.

Port	Year	BCC Efficiency	CCR Efficiency
Abidjan	2011	1	0.415724318
Abidjan	2012	1	0.482295962
Abidjan	2013	1	0.494421131
Abidjan	2014	1	0.465933033
Abidjan	2015	1	0.487580609
Abidjan	2016	1	0.483612179
Abidjan	2017	1	0.504880107
Abidjan	2018	1	0.513266612
Abidjan	2019	1	0.556026911
Abidjan	2020	1	0.578335639
Abidjan	2021	1	0.599003281
Abidjan	2022	1	0.639792298
Abidjan	2023	1	0.942042016
Abidjan	2024	1	0.988044819
Tema	2011	0.714285714	0.289289656
Tema	2012	0.714285714	0.315026877
Tema	2013	0.714285714	0.321811376
Tema	2014	0.714285714	0.279919166
Tema	2015	0.714285714	0.29907522
Tema	2016	0.714285714	0.341629406
Tema	2017	0.714285714	0.365529755
Tema	2018	0.714285714	0.384904046
Tema	2019	0.714285714	0.382557697
Tema	2020	0.714333225	0.477267793
Tema	2021	0.726279224	0.580673025
Tema	2022	0.714285714	0.460764234
Tema	2023	0.714285714	0.455088126
Tema	2024	0.716285719	0.485086175
Lagos	2011	1	0.413817855
Lagos	2012	1	0.433829452
Lagos	2013	1	0.48904067
Lagos	2014	1	0.522439641
Lagos	2015	1	0.772430897
Lagos	2016	1	0.39940921
Lagos	2017	1	0.635314508
Lagos	2018	1	0.493130189
Lagos	2019	1	0.508543356
Lagos	2020	1	0.529015091
Lagos	2021	1	1
Lagos	2022	1	0.771549539
Lagos	2023	1	0.771549539
Lagos	2024	1	0.861657670
Lome	2011	0.981651376	0.179735148
Lome	2012	0.981651376	0.14701137
Lome	2013	0.981651376	0.158741969
Lome	2014	0.981651376	0.194056578
Lome	2015	0.981651376	0.461549281
Lome	2016	0.981651376	0.418711372
Lome	2017	0.981651376	0.608387385
Lome	2018	0.984042861	0.711272565
Lome	2019	0.986996688	0.764718922
Lome	2020	0.993324077	0.87920628
Lome	2021	1	1
Lome	2022	0.99973455	0.995196973
Lome	2023	0.998245244	0.968249568
Lome	2024	0.899255579	1

Data Source: [13], [14], [15], [16]

Abidjan exhibited consistently high operational efficiency,

achieving a BCC efficiency score of 1.000 across all years, indicating strong internal management and resource utilization. However, its CCR efficiency scores varied significantly, starting at 0.4157 in 2011 and progressively increasing to 0.9880 in 2024. This upward trend suggests that while Abidjan was effectively managed, scale inefficiencies persisted, likely due to infrastructure limitations or capacity mismatches. The steady improvement over time reflects targeted investments in port modernization and expanded handling capacity.

Tema demonstrated relatively stable but lower efficiency levels. The BCC efficiency remained nearly constant at 0.714, with a slight increase to 0.726 in 2021. However, the CCR efficiency was considerably lower, beginning at 0.289 in 2011 and peaking at 0.580 in 2021 before slightly declining in the following years. The significant gap between BCC and CCR scores indicates persistent scale inefficiencies, suggesting that Team's operational practices were efficient, but limited infrastructure or congestion issues constrained overall productivity.

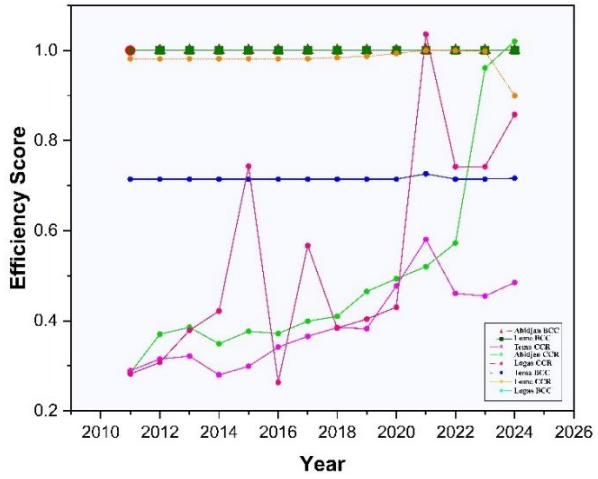

Figure 3. Trend of CCR and BCC Efficiency Score (2011-2024)

Lagos maintained a high level of operational efficiency, with a BCC score of 1.000 throughout the study period. However, its CCR efficiency fluctuated, beginning at 0.4138 in 2011 and improving to 1.000 in 2021 before declining to 0.7715 in 2022 to 2024. The variations in CCR efficiency suggest that while Lagos operated efficiently at the managerial level, external factors such as congestion and infrastructure capacity influenced its overall technical efficiency. The peak in 2021 implies that investments in expansion and automation contributed to improved efficiency, but the subsequent decline indicates the growing pressure of increased trade volumes.

Lomé emerged as the most efficient port in the study, with consistently high performance in both models. The BCC efficiency scores remained close to 1.000, achieving full efficiency in 2021. Meanwhile, its CCR efficiency showed the most remarkable improvement, rising from 0.1797 in 2011 to 1.000 in 2021, and 2024 demonstrating a well-balanced approach to operational and scale efficiency. Unlike other ports, Lomé sustained its high efficiency in the later years of the study, with CCR scores remaining above 0.95 in both 2022 and 2023. This suggests that Lomé benefited from well-planned infrastructure expansion, effective cargo-handling systems, and its strategic role as a transhipment hub.

4.1. Comparative Analysis

Lomé stands out as the most efficient port, consistently maintaining near-optimal BCC efficiency while showing significant improvement in CCR efficiency, reaching 1.000 in 2021. This suggests that Lomé operates with strong managerial efficiency and has effectively scaled its operations.

Lagos also achieves a perfect BCC score throughout the period, indicating strong operational efficiency. However, its fluctuating CCR scores reveal scale inefficiencies, with congestion and operational constraints affecting overall performance. While Lagos reached a CCR efficiency of 1.000 in 2021, lower scores in other years indicate challenges in maintaining efficiency at higher operational levels. Abidjan exhibits consistent BCC efficiency of 1.000 but shows gradual CCR improvement from 0.4157 in 2011 to 0.9880 in 2024. This pattern suggests effective management practices but lingering inefficiencies at scale. The port's steady progress reflects ongoing infrastructure and capacity enhancements. Tema ranks lowest in efficiency, with BCC scores stagnating at 0.714 and CCR scores peaking at just 0.5807 in 2021. The persistent gap between its BCC and CCR scores indicates inefficiencies at both operational and scale levels, limiting its competitiveness in the region. Fig. 4 visually compares port performance, clearly illustrating Lomé's dominance and Tema is lower efficiency.

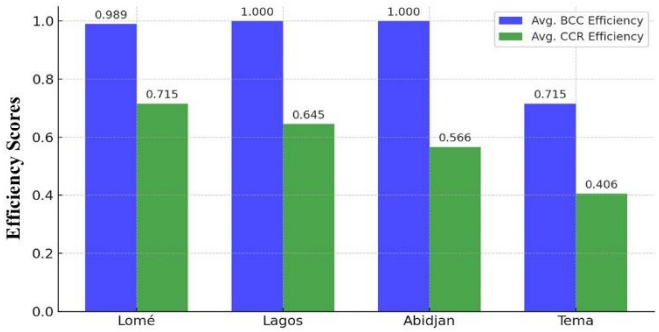

Figure 4. Comparison of Average BCC and CCR Efficiency Scores in 2024

5. SWOT Analysis

The SWOT analysis provides a comprehensive evaluation of the strengths, weaknesses, opportunities, and threats associated with the major ECOWAS ports—Lagos, Abidjan, Tema, and Lomé. Fig. 5 below offers a visual representation of these factors, highlighting the strategic positioning of each port based on its performance, infrastructure, and external challenges.

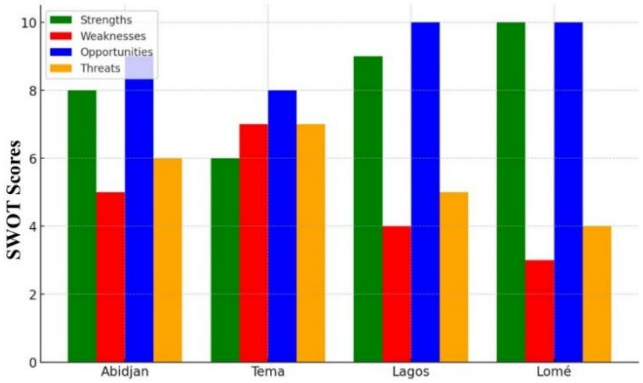

Figure 5. SWOT Summary of ECOWAS Ports

The Port of Lomé demonstrates strength with consistently high BCC efficiency scores of 1.0, reflecting optimal resource utilization, supported by deep-water berths and advanced cargo-handling systems, positioning it as a transhipment hub

for landlocked countries. However, weaknesses were evident in its early years, with low CCR efficiency (0.1797 in 2011), indicating scale inefficiencies that required major infrastructure upgrades. Opportunities lie in enhancing AfCFTA integration and expanding multimodal connectivity, which could further strengthen its position [48]. However, threats include growing competition from Lagos and Abidjan and economic instability in Togo, which could affect future performance.

The Port of Lagos, as West Africa's largest port, has strengths in its strategic location and consistent BCC efficiency scores of 1.0, highlighting strong technical efficiency and resource management. Despite this, weaknesses exist due to fluctuating CCR scores (ranging from 0.413 in 2011 to 1.0 in 2021), reflecting congestion and infrastructure bottlenecks. Opportunities for Lagos include leveraging public-private partnerships (PPPs) and automation technologies to enhance operational efficiency and reduce delays [49]. However, threats such as increasing competition from Lomé and Abidjan, along with Nigeria's economic instability, could hinder sustained efficiency improvements [50].The Port of Abidjan possesses strengths in modern infrastructure and a strong regional trade role, with CCR efficiency improving from 0.4157 in 2011 to 0.9880 in 2024 while maintaining BCC efficiency at 1.0, demonstrating high operational efficiency [51]. Its weakness lies in its dependence on the Vridi Canal, which limits its ability to accommodate larger vessels and creates scale inefficiencies [52]. Opportunities include ongoing terminal expansions and trade corridor developments, which enhance its ability to attract larger trade volumes [53]. Nevertheless, threats such as growing competition from Lomé and Lagos and global trade fluctuations pose challenges to long-term sustainability. The Port of Tema, Ghana's primary trade hub, has strengths in its strategic location along the Gulf of Guinea and stable BCC efficiency scores averaging 0.714, which contribute to steady operational performance[54]. However, its weaknesses include low CCR efficiency, peaking at 0.580 in 2021, pointing to scale inefficiencies caused by limited berth capacity and underutilized resources. Opportunities exist in planned modernization projects and deeper regional trade integration, which could improve its competitive position. Yet, threats such as rising efficiency in Lomé and Abidjan and persistent infrastructure constraints continue to challenge Tema's ability to compete effectively within the region.

6. Discussion

6.1. Interpretation of Results

The DEA and SWOT analyses provide critical insights into the operational efficiency and strategic positioning of Lomé, Lagos, Abidjan, and Tema. Lomé demonstrated the most significant efficiency gains, with CCR scores rising from 0.17 in 2011 to a perfect 1.0 by 2021, reflecting deep-water harbor expansion, advanced cargo handling, and its role as a transhipment hub for landlocked countries. Its consistently perfect BCC efficiency further highlights optimal resource utilization.

Abidjan also showed strong improvement, with CCR efficiency increasing from 0.41 in 2011 to 0.94 in 2023, driven by Vridi Canal expansion and infrastructure modernization, enhancing its ability to accommodate larger vessels and facilitate regional trade. However, its reliance on the canal creates scale inefficiencies, limiting long-term capacity growth. Tema port ongoing terminal expansions present an opportunity to strengthen its competitiveness's, in contrast, faced persistent scale inefficiencies, with CCR efficiency peaking at 0.58 and BCC efficiency averaging 0.714, reflecting infrastructure bottlenecks and underutilized berth capacity. Its strategic location and modernization projects offer potential for efficiency gains, provided investments are directed toward improving operational capacity Lagos, as the region's largest port, experienced CCR efficiency fluctuations (0.413 in 2011 to 1.0 in 2021), highlighting congestion and inconsistent resource management. However, its consistent BCC efficiency of 1.0 confirms strong technical efficiency and robust infrastructure. Opportunities lie in automation and public-private partnerships (PPPs) to enhance capacity and reduce bottlenecks.

Overall, the findings underscore the importance of infrastructure investment, operational efficiency, and regional trade integration. Lomé and Abidjan exemplify the benefits of targeted infrastructure expansion, while Lagos and Tema highlight the need for sustained reforms to overcome inefficiencies. Addressing these disparities is crucial for strengthening ECOWAS port competitiveness and advancing regional trade efficiency.

6.2. Recommendations for Improvement

To improve operational efficiency and competitiveness, ECOWAS ports must adopt a mix of short-term and long-term strategies. In the short term, streamlining customs procedures is essential to reduce delays and congestion, particularly at Lagos and Tema, where inefficient clearance processes hinder cargo throughput. The emphasizes the importance of simplifying customs clearance processes, improving coordination among stakeholders, and adopting digital systems to reduce delays and improve port efficiency [55]. Implementing digitalized customs systems will enhance clearance speed and reduce turnaround times.

Additionally, automation technologies, such as automated cargo handling systems and smart traffic management, can optimize CCR efficiency and alleviate congestion at high-volume ports like Lagos. the importance of automation technologies like robotics, IoT, and AI to improve operational efficiency and productivity, helping to optimize port operations and reduce bottlenecks [56].

For the long term, infrastructure expansion is critical. Ports should invest in new container terminals, additional berths, and enhanced crane capacity to meet growing trade demands. Abidjan's Vridi Canal, for example, requires further dredging and expansion to accommodate larger vessels and maintain regional competitiveness. As emphasized by Samuel et al., the recent modifications to the canal, including its deepening and widening between 2016 and 2018, have already improved its operational capacity. However, to sustain this momentum and ensure the canal remains a player in the regional maritime industry, ongoing dredging is essential, particularly in light of the increasing demand for larger vessels [57]. Furthermore, Pale (2024) suggested that incorporating advanced technologies, such as artificial intelligence and data analytics, could complement the physical infrastructure improvements by optimizing port management and enhancing efficiency, ultimately bolstering Abidjan's competitiveness in the region [58].

Public-private partnerships (PPPs) can drive financing for such large-scale developments, as seen in Lomé's success in

attracting private investments to enhance transhipment capabilities [59].

Regulatory reforms are also necessary to align ECOWAS ports with international standards, improving governance, transparency, and efficiency [60]. Furthermore, integrating sustainability initiatives, such as green port policies, energy-efficient logistics, and waste reduction programs, will strengthen long-term competitiveness. Enhancing multimodal connectivity by investing in rail and inland waterway linkages can reduce logistics costs and improve hinterland access, particularly benefiting ports like Tema and Cotonou, which serve landlocked trade routes.

By implementing these measures, ECOWAS ports can enhance efficiency, optimize resource utilization, and strengthen regional trade integration. Addressing key inefficiencies in customs procedures, infrastructure development, and operational capacity will drive sustainable growth and improve the global competitiveness of West African ports.

6.3. Future Research Directions

Future research on ECOWAS ports should focus on multimodal transport networks, assessing the efficiency of rail, road, and inland waterways in linking ports to landlocked countries like Burkina Faso, Mali, and Niger, optimizing connectivity and reducing logistics costs [61]. Another area is digitalization and automation, exploring the impact of blockchain-based customs systems, AI-driven cargo handling, and port management software on operational efficiency [62].

The adoption of sustainability initiatives, including renewable energy, eco-friendly infrastructure, and emission-reduction strategies, should also be examined to align ECOWAS ports with global environmental standards. These efforts are crucial for reducing emissions and enhancing energy security, as renewable energy sources like solar, wind, and hydro, along with technologies like carbon capture and storage (CCS), play a significant role in mitigating climate change [63]. Comparative research on port competitiveness could benchmark ECOWAS ports against East Asian and Middle Eastern ports, identifying best practices in infrastructure development and trade facilitation. Additionally, studies should analysed the economic and policy impacts of the AfCFTA, focusing on how regulatory reforms can enhance efficiency and trade expansion by simplifying trade regulations, harmonizing customs procedures, and reducing non-tariff barriers to improve cross-border trade and logistics [64]. Research should also address the resilience of ECOWAS ports to external shocks, such as pandemics, economic crises, and supply chain disruptions, to develop contingency strategies for sustained operations. Finally, evaluating the social and economic impacts of port development, including employment creation, urbanization, and regional economic growth, will provide a holistic view of how port investments drive sustainable development.

By exploring these areas, future research can contribute to improving ECOWAS port efficiency, strengthening regional trade integration, and ensuring long-term sustainability.

7. Conclusion

This study assessed the efficiency of four major ECOWAS ports—Abidjan, Tema, Lagos, and Lomé—using Data Envelopment Analysis (DEA) and SWOT analysis to evaluate their operational and strategic performance from 2011 to 2024. The findings reveal that Lomé is the most efficient port, achieving consistent CCR and BCC scores of 1.0, largely due to strategic investments in transhipment infrastructure and operational enhancements. Lagos, despite maintaining high technical efficiency, faces scale inefficiencies due to congestion and infrastructure bottlenecks. Abidjan has shown steady improvement, driven by infrastructure expansions, yet its dependency on the Vridi Canal remains a challenge. Tema, ranking the lowest in efficiency, struggles with scale inefficiencies and infrastructure constraints, limiting its ability to compete effectively.

The study highlights the crucial role of infrastructure investments, operational efficiency, and trade integration in enhancing port performance. Policy recommendations include automation, multimodal transport expansion, regulatory reforms, and public-private partnerships (PPPs) to improve port efficiency and regional trade facilitation. Addressing scale inefficiencies, congestion issues, and technological gaps will be essential for ensuring sustainable growth and enhancing ECOWAS's global trade position.

Future research should explore the impact of digitalization, sustainability initiatives, and economic policy changes on port operations, providing further insights into optimizing efficiency and strengthening regional connectivity. These findings offer valuable guidance for policymakers, port authorities, and trade stakeholders in developing strategic solutions to enhance the competitiveness of ECOWAS ports

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Ethical Approval Statement

This research did not involve any human participants or animals, and therefore ethical approval was not required. All procedures related to data collection and analysis complied with institutional guidelines and ethical standards.

Data Availability:

The data used to support the findings of this study are included in the article.

Conflicts of Interest:

The authors declare no conflict of interest.

Author Contributions

D.Z, A.A, R.T.N: conceptualization, writing-review, data collection, manuscript drafting and supervision of the study; Z.H: investigation, validation; D.Z: design, data collection; A.A: investigation, editing; D.Z:; R.M: data analysis, editing; Z.H, O.O: editing, supervision

Consent to Participate and Publish

All authors have reviewed and approved the final manuscript for publication. All authors consent to participate in this research and agree to its publication.

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