Materials Research Proceedings 64 (2026) 935-942 https://doi.org/10.21741/9781644904091-116

Energy Efficiency and Environmental Performance in Moroccan Port Terminals: An Empirical Assessment

Deyae ENNAYER[1,a *], Nissrine MAJIT[1,b] and Naila AMROUS[1,c]

[1]School of Information Sciences, Rabat, Morocco

[a]deyae.ennayer@esi.ac.ma, [b] nissrine.majit@esi.ac.ma, [c]namrous@esi.ac.ma

Keywords: Energy Efficiency; Environmental Performance; Corporate Social Responsibility; Moroccan Ports; Sustainability

Abstract. This empirical study explores the relationship between energy efficiency initiatives and environmental performance in the Moroccan port sector, focusing on the sites of Casablanca and Tanger Med. The objective is to assess how energy optimization, renewable energy integration, and carbon emission reduction contribute to improving the environmental sustainability of port operations. The research adopts a mixed-method approach combining on-site observations, semi-structured interviews with technical managers, and analysis of energy performance indicators collected directly from the two ports. Findings reveal that energy efficiency strategies have a measurable impact on reducing carbon emissions and enhancing overall environmental performance, with a reduction of energy consumption of approximately 14% at Tanger Med and 10% at Casablanca, and a reduction of CO_2 emissions of 25% at Tanger Med compared to 17% at Casablanca. The study highlights the role of energy management as a strategic driver of sustainability in Moroccan ports.

1. Introduction

The port sector plays a strategic role in international trade and economic attractiveness, yet it remains highly energy-intensive, with significant environmental impacts. In a global context marked by the energy transition, energy efficiency has emerged as a key lever for environmental performance and sustainability [1,2]. Ports, as complex infrastructures, require large amounts of energy to operate handling equipment, logistics facilities, and auxiliary services.

In this context, the main challenge lies in reconciling operational performance with environmental responsibility. A leading Moroccan port operator reflects this dynamic by modernizing its infrastructure, integrating renewable energy sources, and digitizing its processes, in line with the national energy transition strategy.

Empirical studies exploring the relationship between energy efficiency and environmental performance in African ports remain scarce. This research therefore aims to assess to what extent energy efficiency initiatives can improve the environmental outcomes of Moroccan port terminals.

Recent empirical studies conducted in North Africa and the Mediterranean region highlight the growing role of renewable energy systems and energy efficiency measures in reducing energy consumption and CO_2 emissions in port infrastructures, providing valuable regional insights into sustainability transitions [3,4]. In parallel, European and international research on green and smart ports offers relevant benchmarks, demonstrating how technological innovation, digitalization, and energy management practices contribute to improved environmental performance and long-term port competitiveness [5,6]

Based on a mixed-methods approach combining interviews, observations, and quantitative analysis of energy and environmental data from Casablanca and Tanger Med, it highlights the strategic contribution of energy management to port sustainability.

The article is structured as follows: the first section presents the theoretical and conceptual framework linking energy efficiency to environmental performance. The second section describes

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 license. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under license by Materials Research Forum LLC.

the research methodology. The third section presents and discusses empirical results. The article concludes with the study's limitations and future research perspectives.

2. Framework and Methodology

2.1 Theoretical and Conceptual Framework

2.1.1 Key Concepts

Energy Efficiency: According to the United Nations Sustainable Development Goals (SDGs), particularly SDG 7 "Affordable and Clean Energy," energy efficiency aims to substantially increase the global rate of improvement in energy efficiency by 2030 [7].

The International Energy Agency [8] defines energy efficiency as "the process of using less energy to provide the same or improved level of energy service in an economically efficient way", that is, an approach that seeks to reduce energy demand while maintaining productivity and service quality.

Environmental Performance: Environmental performance refers to an organization's ability to manage its environmental impacts and continuously improve its sustainability practices.

The ISO 14001 standard [9] defines environmental performance as "the measurable results of an organization's environmental management system related to its control of environmental aspects."

It includes compliance with regulations, pollution prevention, emission reduction, and the sustainable management of natural resources.

The Global Reporting Initiative (GRI) complements this definition by identifying environmental performance indicators such as energy consumption, greenhouse gas emissions, water and waste management, and the use of renewable energy [10].

Link to the Sustainable Development Goals (SDGs 7 and 13): The analysis of the relationship between energy efficiency and environmental performance fits within the framework of the United Nations Sustainable Development Goals:

- **SDG 7:** *Affordable and Clean Energy* aims to "ensure access to affordable, reliable, sustainable, and modern energy for all" and to "substantially increase the global rate of improvement in energy efficiency" [7].
- **SDG 13:** *Climate Action* promotes reducing greenhouse gas emissions, strengthening climate resilience, and adopting mitigation policies [7].

These two goals provide an international regulatory framework for aligning energy efficiency with the reduction of environmental impacts to achieve overall performance in port sustainability.

2.1.2 Theoretical Framework

Triple Bottom Line Theory (Elkington, 1997): The Triple Bottom Line theory posits that an organization's performance is not limited to the economic dimension but also encompasses environmental and social dimensions [11,13].

Dynamic Capabilities Theory (Teece, 2007): According to the dynamic capabilities theory developed by Teece, Pisano, and Shuen (1997) and further elaborated by Teece (2007), a firm's sustainable competitive advantage lies in its ability to adapt, integrate, and reconfigure resources in response to environmental changes [14,15].

Institutional Theory (DiMaggio and Powell, 1983): Institutional theory explains how organizations adopt certain practices due to normative pressures exerted by their institutional environment [16].

Based on this theoretical framework, this research aims to analyze energy efficiency as a strategic lever for environmental performance and port sustainability. The synergy between technological innovation, institutional compliance, and social responsibility helps explain how energy management influences overall performance in Moroccan port terminals.

While empirical studies on African ports remain limited, existing research on European ports such as Rotterdam and Antwerp highlights the effectiveness of energy efficiency measures in reducing emissions and improving sustainability performance, offering valuable benchmarks for emerging port systems [4].

2.2 Research Methodology

2.2.1 Case Study

The case study focuses on a leading Moroccan port operator, multi-traffic and multi-site, operating 25 terminals and 4 subsidiaries, with a strategic presence in Morocco and across Africa. With over 2,000 employees, the group operates in both import-export and transshipment markets, offering a full range of port services dedicated to cargo and vessels, including piloting, towing, mooring, onboard and quay handling, warehousing, container stuffing and stripping, among others. Two port sites provide a relevant analytical framework: *The Port of Casablanca*, a historical infrastructure undergoing modernization, facing urban and energy constraints; and *The Port of Tanger Med*, a more recent and technologically advanced platform designed with efficiency and sustainability principles from its inception.

The comparative analysis of these two terminals enables assessment of how energy efficiency policies impact environmental performance in distinct yet complementary contexts.

2.2.2 Research Instruments

This research adopts an empirical and exploratory approach, aiming to understand the extent to which energy efficiency initiatives influence environmental performance in the Moroccan port sector.

Energy consumption data were collected from internal energy monitoring systems deployed at terminal level, including smart meters and centralized dashboards. CO_2 emissions were calculated using standardized emission factors applied to electricity and fuel consumption, in accordance with national and international guidelines.

Direct Observation: Direct observation allowed us to identify practices, technologies, and challenges related to energy management, as well as initiatives implemented to improve environmental performance.

Observation was conducted continuously over a six-month period, from May to October 2025, within the studied port operator. Our prolonged presence enabled us to link observed internal dynamics (operational processes, energy behaviors, interactions between technical departments and environmental managers) to measurable outcomes in terms of energy efficiency and emission reduction.

Semi-Structured Interviews: Semi-structured interviews with managers followed a structured yet exploratory approach to collect detailed insights into energy monitoring systems and consumption reduction strategies.

Fifteen participants were interviewed, representing different hierarchical levels and key functions (department heads, division chiefs, energy engineers, maintenance managers, and directors).

The selection of these interviewees was justified by their direct involvement in designing, implementing, and monitoring energy efficiency initiatives, as well as defining the company's environmental policies.

The interviews focused on four main dimensions:

1. Existing energy monitoring practices;
2. Decision-making processes related to energy investments;
3. Perceived barriers to energy efficiency;
4. Environmental performance objectives and indicators.

3. Research Findings and Analysis

The data collected from the Casablanca and Tangier Med terminals make it possible to measure the evolution of energy and environmental performance over the 2021–2024 period.

3.1 Evolution of Energy Consumption

The following figure illustrates the evolution of total energy consumption in both terminals between 2021 and 2024.

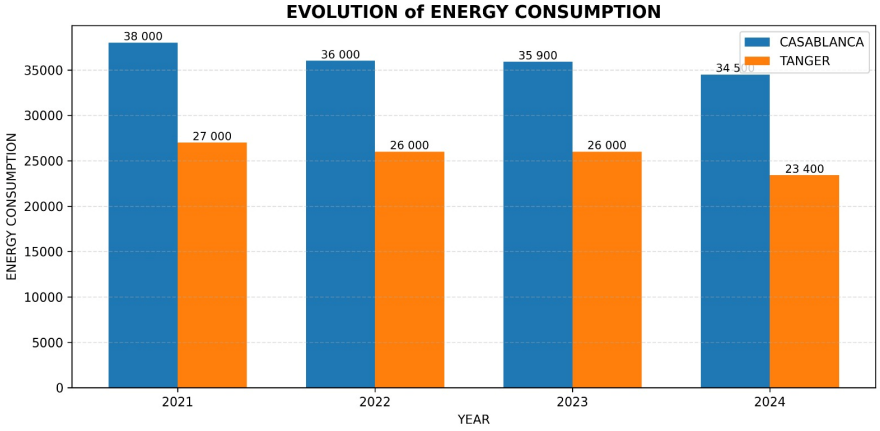


Figure 1. Evolution of total electricity consumption (MWh) in Casablanca and Tanger Med erminals (2021–2024)

The figure shows a gradual decrease in energy consumption at both sites over four years, more significant at Tanger Med (–14%) than at Casablanca (–10%).
This decrease can be mainly attributed to:

1. The modernization of handling equipment (progressive adoption of electric solutions),
2. The implementation of LED lighting systems, and
3. The optimization of operational cycles through the digitalization of energy monitoring.

These results demonstrate that technological and organizational investments aimed at improving energy efficiency lead to measurable reductions in energy consumption.

3.2 Reduction of CO_2 Emissions

The following figure illustrates the reduction of carbon emissions over the same four-year period.

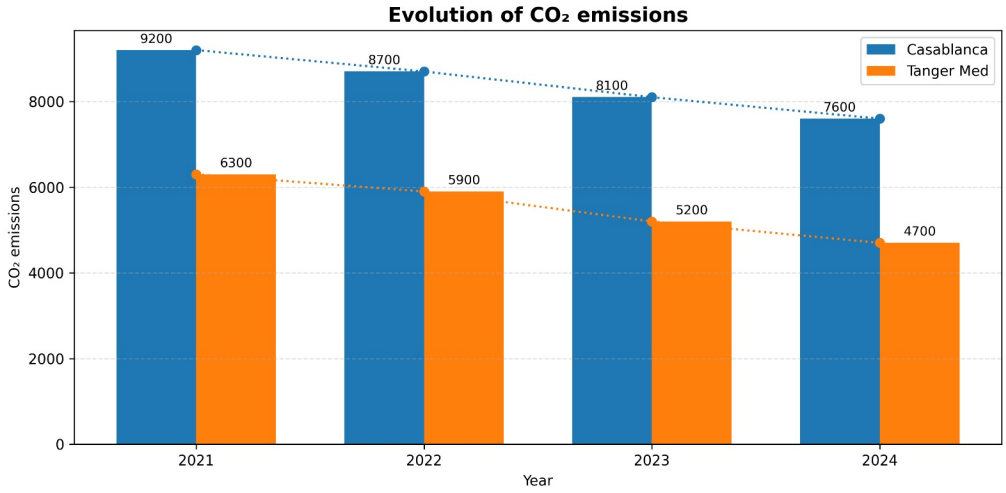


Figure 2. Evolution of CO_2 Emissions (tCO_2e, 2021–2024)

Parallel to the reduction in energy consumption, CO_2 emissions also declined over the same period, reflecting a positive relationship between energy efficiency and environmental performance.

A 25% reduction was recorded at Tanger Med, compared with 17% at Casablanca. This observed difference can be explained by the integration of renewable energy sources such as photovoltaic and solar lighting systems, as well as by a higher level of operational automation.

3.3 Share of Renewable Energy

The following figure illustrates the share of renewable energy in the energy mix.

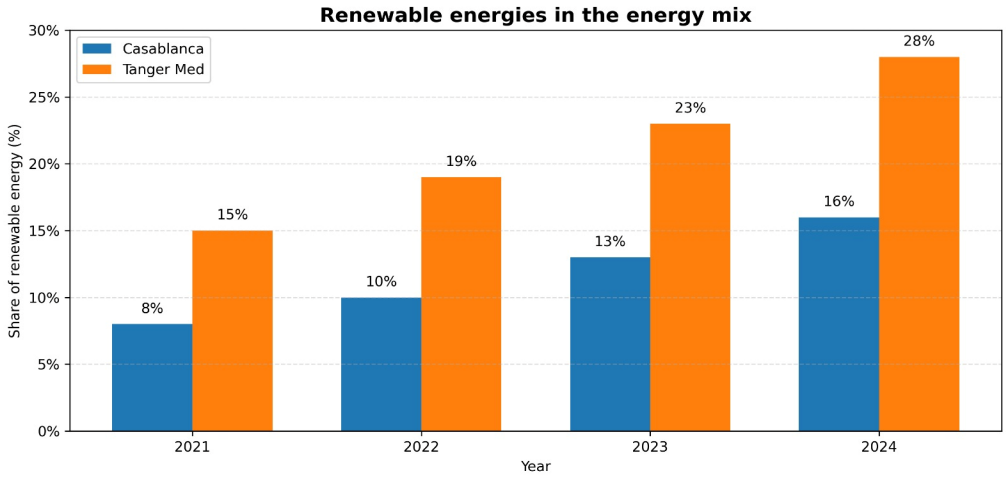


Figure 3. Share of Renewable Energy in the Energy Mix (%)

The gradual integration of renewable energy constitutes a central pillar of the energy strategy of both terminals.

The significant increase at Tanger Med (+13 percentage points over four years) is due to the commissioning of solar installations for administrative buildings and logistics areas. Casablanca shows a more moderate progression, mainly due to the complexity of its urban environment, but confirms a clear orientation toward more sustainable energy management.

3.4 EPI: Environmental Performance Index

The Environmental Performance Index (EPI) provides a composite measure of key dimensions of operational sustainability, namely energy consumption, CO_2 emissions, and the share of renewable energy in the energy mix.

In accordance with the principles of ISO 14001 and the Global Reporting Initiative (GRI) standards, each variable was normalized over the 2021–2024 period and aggregated into a global index ranging from 0 to 100. This equal weighting among the three components allows the monitoring of environmental performance trends across port sites.

The results show a continuous improvement in the EPI for both terminals, reflecting sustained efforts in energy efficiency and emission reduction.

At the Port of Tanger Med, the EPI reached 100 points in 2024, compared with 58 in 2021, illustrating the growing impact of energy modernization and renewable integration initiatives, such as the installation of intelligent energy monitoring systems, optimization of port lighting, and deployment of photovoltaic panels on several operational buildings.

The Port of Casablanca shows a more moderate progression, with the EPI increasing from 0 to 34 points over the same period. This evolution can be explained by the site's structural complexity, urban constraints limiting the rapid integration of green technologies, and a more gradual pace of equipment modernization. Nevertheless, actions such as rationalizing electricity consumption,

modernizing port cranes, and strengthening the environmental management system have significantly improved overall performance.

It is important to note that the Environmental Performance Index (EPI) was constructed using a reference-year normalization approach, with 2021 selected as the baseline year. Each indicator (energy consumption, CO_2 emissions, and renewable energy share) was normalized relative to this reference in order to capture performance changes over time. Equal weighting was applied to the three components to avoid subjective bias. Given the limited temporal scope and small sample size, the analysis relies on descriptive statistics and trend-based comparisons rather than inferential statistical testing

3.5 Discussion of results

The empirical results highlight a positive and significant correlation between energy efficiency and environmental performance in Moroccan port terminals.

The decline in energy consumption observed between 2021 and 2024, combined with the reduction in CO_2 emissions and the increased share of renewable energy, clearly illustrates the strategic role of energy efficiency policies in enhancing operational sustainability.

In line with the Triple Bottom Line theory, the initiatives implemented in the studied ports reveal a synergy among the economic, environmental, and social dimensions of performance.

Economically, reduced energy consumption translates into lower operating costs; environmentally, lower CO_2 emissions reflect improved ecological performance; socially, employee awareness and the promotion of an energy-responsible culture strengthen internal cohesion and organizational commitment.

These findings are consistent with the work of Broccardo et al. [2] and Cardinali & De Giovanni [1], which identify energy efficiency as a central lever for sustainable value creation within organizations.

In accordance with the Dynamic Capabilities Theory, the adoption of technological and digital solutions that promote energy efficiency illustrates the adaptability and innovative capacity of port operators.

Observed practices such as the modernization of cranes, the installation of energy monitoring sensors, and the integration of renewable energy demonstrate organizational agility and a commitment to continuous innovation, creating a virtuous dynamic where energy efficiency becomes a sustainable strategic capability.

The results also underline the role of institutional pressures in adopting responsible energy practices.

Consideration of the Sustainable Development Goals (SDGs 7 and 13), compliance with ISO 14001 standards, and international commitments to reducing port emissions are key factors driving strategic alignment.

These findings confirm Institutional Theory, which posits that organizations adopt sustainable practices to meet legitimate requirements and align with regulatory and societal expectations.

Conclusion and Perspectives

The results obtained clearly demonstrate that energy efficiency constitutes a major strategic lever for environmental performance in Moroccan port terminals.

Beyond the observed technical gains, the initiatives implemented reflect a profound organizational transformation, characterized by process digitalization, regulatory compliance, and the mobilization of internal stakeholders around a shared vision of sustainability. These dynamics mark the evolution toward a more resilient and responsible port model capable of reconciling economic competitiveness with environmental commitment.

This research contributes to a better understanding of how energy efficiency is integrated into the sustainability strategies of port operators in emerging economies. It highlights how technological

investments, innovation, and energy governance drive the transition toward greener and smarter ports.

However, as with any empirical study, certain limitations exist. First, the analysis focuses on a limited sample of two port sites, which restricts the generalization of findings to the broader sector. Second, the social dimension of sustainability, particularly the effects on employment, working conditions, and community perceptions, has not been examined in depth at this stage.

Future research could further develop these findings by expanding the analysis to other Moroccan and African ports, examining the role of leadership and organizational culture in adopting energy-efficient technologies, and developing a multivariable quantitative model integrating digital maturity, terminal size, and environmental investments.

In conclusion, energy efficiency stands as a central pillar of port sustainability, enhancing infrastructure competitiveness while addressing global climate imperatives. The transition toward integrated energy management—based on data, innovation, and social responsibility—has become an essential condition for the sustainable transformation of the Moroccan port sector.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

The authors declare that DeepL was used solely as a translation tool during the preparation of this manuscript. The article was initially written in French and then translated into English using DeepL. The authors reviewed and revised the translated version and take full responsibility for the content. The French version was not submitted or published elsewhere. This article is original and is published exclusively by the current publisher.

References

[1] Cardinali PG, De Giovanni P. Responsible digitalization through digital technologies and green practices. Corporate Social Responsibility and Environmental Management. 2022;29(4):984–995. https://doi.org/10.1002/csr.2249

[2] Broccardo L, Zicari A, Jabeen F, Bhatti ZA. How digitalization supports a sustainable business model: A literature review. Technological Forecasting and Social Change. 2023; 187:122146. https://doi.org/10.1016/j.techfore.2022.122146

[3] Elkafas AG, Seddiek IS. Application of renewable energy systems in seaports towards sustainability and decarbonization: Energy, environmental and economic assessment. Renewable Energy. 2024;228:120690. https://doi.org/10.1016/j.renene.2024.120690

[4] Bouazza S, Benmamoun Z, Hachimi H. Strategic analysis of hub port competitiveness in the Mediterranean and Northern Europe: A focus on sustainability and efficiency. AIMS Environmental Science. 2024;11(2):184–220. https://doi.org/10.3934/environsci.2024010

[5] Elhussieny AA. Smart green ports: A sustainable solution for the maritime industry in a changing climate. Multidisciplinary Adaptive Climate Insights. 2025; published online Feb 10 2025. https://apc.aast.edu/ojs/index.php/MACI/article/view/MACI.2025.02.1.1162/pdf_11

[6] Greening seaports: evaluating impacts and policies for renewable energy systems. Renewable and Sustainable Energy Reviews. 2025;213:115475. https://doi.org/10.1016/j.rser.2025.115475

[7] Nations Unies. Transformer notre monde : le Programme de développement durable à l'horizon 2030. Organisation des Nations Unies; 2015. Disponible sur : https://sdgs.un.org/fr/goals

[8] International Energy Agency (IEA). Energy Efficiency 2023: Analysis and Outlooks to 2030. Paris: IEA Publications; 2023.

[9] International Organization for Standardization (ISO). ISO 14001:2015 – Environmental Management Systems – Requirements with Guidance for Use. Geneva: ISO; 2015.

[10] Global Reporting Initiative (GRI). GRI Standards: Consolidated Set. Amsterdam: GRI; 2021. Disponible sur : https://www.globalreporting.org

[11] Elkington J. Cannibals with Forks: The Triple Bottom Line of 21st Century Business. Oxford: Capstone Publishing; 1997.

[12] Slaper TF, Hall TJ. The Triple Bottom Line: What is it and how does it work? Indiana Business Review. 2011;86(1):4–8.

[13] Norman W, MacDonald C. Getting to the bottom of "Triple Bottom Line." Business Ethics Quarterly. 2004;14(2):243–262. https://doi.org/10.5840/beq200414211

[14] Teece DJ. Explicating dynamic capabilities: The nature and microfoundations of sustainable enterprise performance. Strategic Management Journal. 2007;28(13):1319–1350. https://doi.org/10.1002/smj.640

[15] Teece DJ, Pisano G, Shuen A. Dynamic capabilities and strategic management. Strategic Management Journal. 1997;18(7):509–533.

[16] DiMaggio PJ, Powell WW. The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields. American Sociological Review. 1983;48(2):147–160.