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Mziwendoda Cyprian Madwe *, Zwelihle Wiseman Nzuza, Odunayo Magret Olurawaju *

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Article

The Impact of Energy Efficiency on Financial Performance: Evidence from Polluters in South Africa

Mziwendoda Cyprian Madwe [1], Zwelihle Wiseman Nzuza [2] and Odunayo Magret Olurawaju [2,*]

[1] Durban University of Technology, South Africa

[2] Zwelihle Wiseman Nzuza, South Africa

* Correspondence: madwem@unizulu.ac.za; Tel.: 071-840-63-23

Abstract

The global fight against greenhouse gas emission and environmental degradation calls for an increase in energy-saving strategies. Addressing the climate change issue while maintaining firm performance is increasingly essential. However, the impact of energy efficiency on corporate financial performance remains unanswered in the prior research, especially in South Africa. This study explored the impact of energy intensity on the financial performance of higher polluters in South Africa Listed on the Johannesburg Stock of Exchange (JSE) over the period 2015 to 2023. The sample for the study was 58 companies listed on the JSE. The data was sourced from the annual firm's annual reports covering the period of 9 years (2015-2025). Two-step system generalized method of moments (SGMM) were employed to examine the relationship between energy efficiency and firm financial performance. Our study reveals no association between energy-saving strategies and firm financial performance within high polluting and emitting firms listed on the JSE. Notably, the study reports that leverage positively impacts both firm profitability and market valuation, suggesting that debts may serve as dynamic capability for improving firm performance if it is used strategically. Our findings underscore the importance of mandatory independent assurance of ESG reports to mitigate greenwashing risks.

Keywords: energy-saving strategies; ESG reports; financial performance; Greenhouse Gas Emission (GHG); mandatory assurance

1. Introduction

The improvement in energy efficiency is crucial for attaining the sustainable developments goals (SDGs) and improving firm profitability. Globally, energy efficiency, has received more intention from firms, governments, researchers and policy makers as an important strategy in attaining sustainable development goals (SDGs) [1–3].

Energy efficiency is cost effective strategy applied to reduce energy consumption and greenhouse gas emissions, which is important in climate change challenges [4–6]. Energy-saving mechanisms are essential tools for mitigating environmental degradation and reducing energy costs [7,8]. Energy efficiency promotes eco-friendly practices and environmental sustainability by prompting green economy and addressing carbon emission challenges [9]. The energy efficiency strategies generate financial benefits for owners, employees and investors, they also generate social benefits including reduced GHG emissions, more jobs, less dependency fossil fuel, thereby improving growth [10]. According to [11], energy efficiency is a cost-effective strategy to address gas emissions and enhance firm performance and improve efficiency in their operations. Firms that invest in energy efficiency mechanisms mitigate energy costs, meet stakeholders demand for environmentally responsible products, and improve firm's reputation, leading to improve financial performance [12–15]. The adoption of energy-saving strategies positively influences public health by mitigating air pollution, which has severe health implications [16].

Despite these plausible benefits of energy-saving strategies, limited studies have been conducted in South African polluters and emitters to investigate the energy efficacy-firm financial performance

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nexus. Without a comprehensive understanding of this relationship, it is challenging to address energy-related issues. Although energy saving strategies are crucial to mitigate environmental degradation, it still raises concerns due to the inadequate empirical evidence of financial benefits. Without a deeper understanding of financial benefits associated with energy efficiency, firm may consider these environmentally responsible activities burdensome and deteriorating firm performance

Promoting energy efficiency requires substantial investment in energy efficiency technologies [17–20]. These high upfront costs associated with energy-saving strategies remain a hinderance towards attainment of sustainable energy systems. Although energy efficiency involves high upfront costs, they yield cost savings and environmental benefits in long-term [21,22].

The contribution of South African polluters and emitters, such as mining, manufacturing, construction, industrial and consumers good sectors to economic development is essential. However, these industries have high energy intensity, high GHG emission and high populations. Therefore, they have duty to prevent and control depletion and environmental degradation, they should invest in expensive advanced technologies to fulfil their environmentally responsible. Understanding financial gains associated with investing in energy-saving technologies is essential in assisting firms to understand whether these investments are beneficial to both companies and the environment to achieve sustainable development goals (SDGs). Although prior research claims that energy-saving technologies reduce production costs and enhance corporate financial resiliency, a limited empirical understanding of their impact firm performance of polluters and emitters in South Africa remains underexplored. For example, while some researchers reported positive relationship between energy efficiency mechanisms and corporate financial performance [23–25], others documented negative [27,28] and no relationship [29–31].

Considering previous studies investigated the relationship between energy efficiency and firm financial performance, no consensus has been reached on the impact of energy efficiency on firm financial performance. Moreover, the relationship between energy efficiency strategies and financial performance in South African polluters and emitters, such as mining, manufacturing, construction and oil and gas industries is not fully investigated. The gap delays energy-saving technology investments that could improve energy efficiency, thereby improving firm financial performance.

Therefore, there is urgent need to explore the impact of energy efficiency on firm performance in South Africa, particularly in high-polluters and emitters firms. The empirical evidence on the benefits associated with energy efficiency is increasingly critical for introducing interventions that can drive the attainment of more energy-efficient and sustainable firms operation systems. This notion is in line with the growing body of literature, indicating that empirical evidence of financial benefits of adopting energy-saving technologies can encourage companies to invest in these practices, thereby improving firm financial performance [32].

Addressing these gaps, this study seeks to extend the existing literature and explore the impact of energy efficiency on firm financial performance of 58 polluters and emitters listed on Johannesburg Stock Exchange (JSE) for the period of 2015 to 2023. To offer unique perspective, this study employs two-step system GMM in the context under which energy efficiency strategies can contribute to GHG reduction and environmental protection. The findings of this study are intended to make a valuable contribution in energy efficiency- firm performance ongoing debate. The research aims to contribute to the body of knowledge by providing comprehensive analysis of energy efficiency-firm performance nexus. Our research is novel in the sense that focuses on very ignored sectors in South Africa, it also focused on energy intensity as sub-pillar of environmental performance which prior studies ignored.

The research of this paper is structured as follows: section 2 reviews the theories underpinning the study, reviews relevant literature, section 3 details the methodology, section 4 presents key findings on the relationship between energy efficiency and firm financial performance. Section 5 discusses core insights and broader implications, and section 6 concludes with a summary and recommendation for future research.

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2. Review of Literature and Development of Hypotheses

2.1. Agency Theory

Agency theory elucidates the association between shareholders (principals) and Managers (agents), especially when their goals diverge [33]. Agency theory assumes that managers may act in their own interest rather than those of shareholders. Agency theory indicates the potential for agency costs and conflicts, especially in cases where managers may exploit company resources for personal gains through corporate philanthropy, potentially leading to losses for shareholders [34]. Prior research states that engaging in energy efficiency strategies may reflect managerial agency problems within companies and can be explained through the lenses of agency theory [35]. The investment in energy-saving mechanisms may be driven by the self-interested actions of managers, which result from agency problems and reduce firm profits. According to this theory, agents (managers) of the organisation are under pressure from principals (owners) because of stakeholders' expectations encouraging them to employ environmentally responsible practices to address these pressures [36]. The pressure from stakeholders motivates managers to engage in environmentally responsible practices to gain organisational legitimacy [37]. Managers may resolve the stakeholders' pressure by engaging in a symbolic decoupling strategy known as greenwashing [38]. This symbolic greenwashing is less substantive action that serves as shield for the organisation to avoid being penalized by the stakeholders and regulators. Although this symbolic decoupling strategy may seem profitable in short term, it may damage firms' reputations and legitimacy in long-term

2.2. Stakeholder Theory

Stakeholder theory is common theory applied in corporate management and business ethics [39]. This theory postulates that organisations aim to protect and to generate benefits for stakeholders [40]. Agency theory postulates that the interests of stakeholders are of the utmost importance to firms and the success of organisation depends on how well it meets the needs of stakeholders. This theory posits that organisation success depends on maintaining stakeholders' requirements and gaining legitimacy.

Stakeholders, such as clients, suppliers, regulators, media, shareholders and employees demand transparent and tangible effort to mitigate GHG emissions [41]. Prior research on the environmental performance-firm financial performance has explored the role of stakeholder pressure in explaining this relationship [42,43]. Therefore, this study employed this theory to assess how pressure from stakeholders impacts the relationship between energy efficiency and firm financial performance.

2.3. Institutional Theory

Institutional theory posits that firm behaviour is shaped by accepted and appropriate norms in sector [44]. This theory postulates external institutional pressure, these pressures include regulatory, standards and policy, and stakeholder expectations [45]. According to this theory companies operating sectors and countries with strong regulatory frameworks are more likely to implement environmentally responsible initiatives [46]. Firms must conform with established acceptable social and environmental frameworks to gain stakeholder expectations. Engaging in environmentally responsible practices, such as energy efficiency strategies, is a license to gain legitimacy, secure resources and ensure sustainability [47]. Non-compliance with energy-saving strategies may negatively impact on firm legitimacy, leading to poor firm performance. These non-compliance with environmentally responsible practices come with unbearable fines and penalties, which are relatively higher than costs of implementing environmentally responsible practices [48]. Therefore, environmental compliance such as adoption of energy-saving mechanisms may enable organisations to obtain production efficiency, thereby improving their competitive advantage in the sector.

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2.4. Resource-Based Review (RBV) Theory

The resource-based review (RBV) theory states that firms attain competitive advantage through using organisation capabilities and resources, which are valuable, inimitable, unique and rare [49]. According to this theory, energy-saving technologies are valuable resources that mitigate climate change issues, enabling firms to meet stakeholders and societal expectations, consequently, positively impact firm financial performance [48]. Energy efficiency technologies are the resources that are employed to reduce production costs (energy costs), enhance production efficiency, and reflect commitment to environmentally responsibility activities, thereby improving firm reputation and investor confidence [50].

This study adopted these four theories to explain the relationship between energy efficiency and firm financial performance.

2.5. Relationship Between Energy Efficiency and Firm Financial Performance

There is growing interest in ESG-firm performance research to understand how energy efficiency affects firm financial performance. Firms that adopt energy efficiency strategies may mitigate energy costs and improve operational resilience [51]. Ref. [52] argues that firms with energy efficiency strategies benefit from electricity costs, while those with high energy intensity experienced exorbitant energy production costs. The impact of energy efficiency on firm financial performance has been extensively studied [53–55].

However, prior research on relationship between energy efficiency and firm performance has yielded a contradictory result. For instance, [17,18,50–53] found that environmentally responsible practices positively impact firm performance. Similarly, [56] examined the relationship between energy conservation and firm performance using 400 manufacturing firms in Thailand and reported positive relationship. [57] explored energy intensity and firm performance, the findings indicated a positive relationship between energy efficiency and firm value. In the same vein, [58] examined the impact of energy on firm performance of the top 500 publicly traded US companies. Their study revealed a positive relationship. [59] explored the energy intensity levels between non-energy-intensive and energy-intensive sectors in Thai markets. The results showed that energy efficiency significantly influences firm performance. [60] investigated the association between firm financial performance and firm energy efficiency and revealed positive relationship.

Conversely, some researchers reported a negative relationship between energy-saving strategies and firm performance. For example, [61] investigated impact of energy efficiency on firm performance of 563 firms in 46 countries. The findings reported that energy performance has a negative impact on firm financial performance due to high initial costs. Similarly, [62] found a negative relationship between energy efficiency and firm performance in multinationals firms. [24] reported that high-polluting firms listed on the Western Stock Exchange, energy saving strategies reduced profits and returned assets.

On the other hand, some researchers found no association between energy efficiency and firm financial position. For instance, [63] found no impact of adoption of energy efficiency on firm performance. On the same vein, [26,27] found no relationship between energy efficiency and financial performance in the Baltic Sea Region.

The prior research produces inconsistent findings on the relationship between these two variables, those that promote relationship (positive), those inhibiting association (negative) and no significant relationship. Therefore, the study proposes the following hypothesis:

Hypothesis 1 (H1): Energy efficiency has a positive impact on firm financial performance

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3. Materials and Methods

3.1. Data Description and Data Sources

The sample of the study consists of 58 polluters and emitters listed on the JSE. These companies were included in the sample due to their significant impact on environment, such as high energy intensity, high pollution and consuming a lot of natural resources in South Africa. The Financial data was obtained from firms' annual reports covering the period of nine years (2015 -2023). Energy efficiency data was extracted from ESG reports, in case of missing data, Blomberg was employed as supplementary data source. The two-step system GMM was utilized to explore the impact of energy efficiency on firm performance of JSE-polluters and emitters. The system GMM is widely recognized as powerful econometric model that addresses issues of endogeneity [63]. Two-step GMM enhances accuracy and addresses finite sample bias [64].

3.2. Variable Measurements

The research examines the impact of energy efficiency on financial performance. Following [65–69], return on assets (ROA), return on equity, earnings per share (EPS) and Tobin's Q (TQ) were employed as indicators of financial performance. In line with [70], the study employed the energy intensity improvement ratio (EIIR) to capture energy efficiency. EIIR was calculated using MSCI rating methodology [71]. The energy efficiency was measured by energy used per output unit per MWh/ton. The EIIR is a year-on-year efficiency indicator that measures how much a firm has improved its energy efficiency compared to energy efficiency in previous year. Table 1 illustrates the MSCI's sector-specific weighting method employed to calculate the EIIR score. MSCI rating methodology breaks down environmental performance pillar into sub-pillars, namely, GHG, MWIR, LRR, WUIR and EIIR), then assign raw weights based on the materiality of each sub-pillar within a specific sector. These raw weights are then normalized to ensure consistency approach across different sectors.

Table 1. Environmental performance and sub-weights by Sector.

Pillar	Weight	Total Weigh	Normalised
Environment Protection (GHG, WMIR, LRR)	0.16	0.20	0.80
Product Responsibility (WUIR & EIIR_	0.04	-	0.20

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3.3. Control Variables

In line with prior research, this study controls specific factors to address the issue of omitted variables. The study control firm size, age and leverage [72]. Company's size Company's size is commonly used as a control variable when investigating the relationship between environmental performance and firm performance [73]. Prior research indicates that larger companies are more likely to engage in environmentally responsible activities because they have more resources and stakeholder pressure [74]. The age of a company is widely adopted as measure for experience and maturity. Highly leveraged companies may be reluctant to invest in environmentally responsible practices due to limited financial resources. Table 2 indicates financial performance indicators employed in this study.

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Table 2. Variable Measurements.

Variable	Description	Formula	Source
Dependent Variable	ROA	ROA=$\frac{Net\ Income}{Total\ Assets}$	[75,76]
	ROE	ROE= $\frac{Net\ Income}{Shareholder's\ Equity}$	[77,78]
	EPS	EPS=$\frac{Net\ Income - Pref\ Div}{Weighted\ Ave\ No\ of\ share}$	[79]
	TQ	TQ=$\frac{Market\ Value\ for\ the\ firm}{Replacement\ cost\ of\ assets}$	[80]
Independent Variable	EIIR	EIIR =$\frac{EIIR_{t-1}-EIIR_t}{EIIR_{t-1}}$	[81]
Control Variables	Lev	Lev=$\frac{Total\ Debt}{Total\ Equity}$	[82]
	Firm Size	In (Number of employees)	[83]
	Firm Age	Current year-founding year	[84]

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3.4. Data Analysis

The study analysed the association between energy efficiency and firm financial performance utilising STATA software, version 18. The descriptive analysis was first employed to determine the trend and pattern of energy efficiency and financial performance in integrated or annual reports of 58 firms listed on the JSE. The two-step system GMM was adopted to empirically examine the relationship between energy efficiency and firm financial performance. he SGMM model estimated in this research is specified as:

Short model:

$FS_{it} = \alpha_0 + FS_{it-1} + EE_{it} + \varepsilon_{it}$ …… ……..(1)

Full model:

$FS_{it} = \alpha_0 + \alpha_1\ FS_{it-1} + \beta_1\ EIIR_{it} + \beta_2\ CONTROL_{it} + \varepsilon_{it}$ …….. (1.1)

Model ROA, ROE, EPS & TQ:

$ROA_{it} = \alpha_0 + \alpha_1\ ROA_{it-1} + \beta_1\ EIIR_{it} + \beta_2\ SIZE_{it} + \beta_3\ AGE_{it} + \beta_4\ LEV_{it} + \varepsilon_{it}$ …….. (1.2)

$ROE_{it} = \alpha_0 + \alpha_1\ ROE_{it-1} + \beta_1\ EIIR_{it} + \beta_2\ SIZE_{it} + \beta_3\ AGE_{it} + \beta_4\ LEV_{it} + \varepsilon_{it}$ …….. *(1.3)*

$EPS_{it} = \alpha_0 + \alpha_1\ EPS_{it-1} + \beta_1\ EIIR_{it} + \beta_2\ SIZE_{it} + \beta_3\ AGE_{it} + \beta_4\ LEV_{it} + \varepsilon_{it}$ …….. (1.4)

$TQ_{it} = \alpha_0 + \alpha_1\ TQ_{it-1} + \beta_1\ EIIR_{it} + \beta_2\ SIZE_{it} + \beta_3\ AGE_{it} + \beta_4\ LEV_{it} + \varepsilon_{it}$ …….. *(1.5)*

Where:

FS_{it}: represents financial performance (ROA, ROE, EPS & TQ); α_0: Coefficient for the Lagged variable; β_1-β_5: Coefficients for EIIR; ε_{it}: Error term controlling other variables not included in the financial performance models.

4. Result and Discussion

4.1. Descriptive Statistics

Table 3 depicts the descriptive statistics from a dataset of 522 firm-years observations (9 x 58). Table 3 indicates that firms included in the sample reduce energy consumption by 3% per year. The findings reveal that companies in the high-polluting sectors are engaging in energy saving practices.

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It is observed that sample yields 9.1% of profit from invested assets. Table 3 shows that the sample included both strong performers and underperforming firms.

Table 3. Descriptive analysis.

Variable	Mean	Std. Dev	Min	Max
ROE *	1.691	19.278	-27,402	416.195
ROA	0.081	0.347	-1.136	7.397
EPS	5.780	13.994	-69.91	147.45
	122,202	326,961	-4.399	4738.10
TQ	0.033	0.094	-0.893	0.403

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4.2. Energy Efficiency on Firm Performance Using a Two-Step System GMM

Table 4 presents the two-step system GMM results from four financial performance models. Two-step system GMM was employed to explore the relationship between energy efficiency and firm financial performance of 58 polluters and emitters listed on the JSE. The findings in all models indicate that there is no association between firm financial performance measured by ROA, ROE, EPS & TQ and energy efficiency. This indicates that the adoption of energy efficiency mechanism may not be immediately and might take time for firms to generate tangible benefits (profitability or market valuation benefits) in the study period. These findings reinforce the argument that although environmentally responsible practices are important for long-term sustainability, they may not generate short-to-term financial benefits, especially in resource-intensive industries. These results challenge previous findings by [50–56], who reported a positive relationship between energy efficiency and firm financial performance. This study is consistent with prior results [23,25,26,62] which reported no relationship between energy efficiency and firm financial performance. The study's findings question RBV theory and suggest that energy efficiency is ordinary capability with high probability of imitation and may not be dynamic and unique asset that creates competitive advantage, since it is extensively adopted and now easily imitable, limiting its power to generate higher profits. Agency theory explains these results as where agents may be implementing environmentally responsible practices to conform with regulatory frameworks rather than maximizing principal interests. From stakeholder theory, these results indicate that stakeholder loyalty in the sample may take time to impact firm financial performance. According to institutional theory, these results may suggest that the sample is engaging in greenwashing strategies that may be more about compliance rather than infusing these environmentally responsible practices into core strategies objectives of the firms. As a result, the proposed hypothesis H1 is rejected in all models.

Regarding control variables included in model A, all control variables have insignificant impact on firm financial performance. This indicates that factors such as external pressures, regulatory framework and tax incentives may matter more than control variables included in model A. Leverage exhibits a positive relationship with ROA and TQ, consistent with the notion that firms with higher debt utilize their assets to fund energy efficiency practices to enhance productivity. Table 4 indicates that larger companies perform better than smaller firms in terms of market valuation. This indicates that larger firms may have access to valuable resources that offset complexity and inefficiencies.

Table 4 highlights that energy efficiency in the sample is shaped and explained more by external pressures such as legitimacy and compliance than by tangible financial benefits. It is also observed that firm size and age may not fully influence both environmental performance and financial performance.

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Table 4. Two-Step System GMM.

Variable	ROE Model A	ROA Model B	EPS Model C	TQ Model D
FP(t-1)	0.076 (1.40)	-0.028 (-1.21)	0.263 (1.13)	0.202* (1,72)
EIIR	0.078 (0,02)	0.004 (0.04)	2.751 (0.96)	-25.18 (-0.36)
AGE	-0.001 (0.04)	0.000 (0.64)	0.006 (0.81)	0,051 (0.46)
LEV	0.000 (0.11)	0.001 (7.68) ***	-0.000 (-0.31)	0.285*** (6.89)
SIZE	-0.932 (0.90)	0.005 (0.03)	-1.075 (-0.91)	-40,753*** (-2.16)
Constant	11.520 (1.03)	0.161 (0.84)	14.951 (1.10)	491,031** (2.25)
Observations	522	522	522	522
AR (1)	0.309	0.478	0.224	0.305
AR (2)	0.342	0.723	0.633	0.573
Hansen Test	0.032	0.115	0.269	0.616
Z-statistics in parentheses, *significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level				

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5. Conclusions and Recommendations

This study examines the impact of energy efficiency on firm financial performance 58 of polluters and emitters listed on the JSE in South Africa over the period of nine-years (2015-2023). The study applied two-step system GMM to explore the relationship between energy efficiency and firm financial performance. The study reveals no relationship between energy efficiency and firm financial performance in the sample. The study found that energy-saving strategies often framed as valuable, and rare, and inimitable are insufficient to ensure better financial performance, if it is widely adopted and easily imitable in the sectors, since it loses its power to derive competitive advantage.

We advance the existing knowledge by exploring a mainly ignored association between energy efficiency and firm financial performance, especially in high-pollution and high-carbon emission sectors listed on the JSE in South Africa. Prior research in South African setting have focused on overall environmental performance, neglecting disaggregated sub-pillars such as energy efficiency. This study extends body of knowledge by uncovering that environmentally responsible initiative that is extensively implemented, becomes an ordinary capability with the high probability of imitating and may not fully explain firm performance. In advancing agency theory, this study found information asymmetry as major barrier in the integration of environmentally responsible initiatives in key operational activities. The results suggest that managers may prioritise the environmentally responsible practices at the expense of shareholders to gain legitimacy, firm reputation and to avoid public scrutiny. The study underscores an urgent need for mandatory assurance of ESG performance reports to mitigate greenwashing strategies.

For practical contribution, our findings have important implications for managers, policymakers and stakeholders in South Africa. For managers, the lack of tangible financial gains from investing in environmentally responsible practices highlights the necessity to implement these practices into key organisational operational strategies. Managers should not treat environmentally responsible practices as only marketing and compliance practice. Our findings urge investors to critically assess ESG reports in the situation when independent assurance is not compulsory. For policymakers, the insignificant association encourages the need for stronger regulation, including mandatory ESG assurance to ensure that disclosure performance represents true environmental performance.

While our study provides valuable contribution, it is subject to some limitations. The study focuses only on polluters and emitters listed on the JSE, this may limit generalizability to other sectors. The reported ESG data employed in this study relied on self-reported annal report without mandatory independent assurance, which may trigger bias reporting or greenwashing strategies. The study employed secondary data, which fail to capture experiences and onions of managers regarding factors hindering this relationship.

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Future researchers could address these gaps by considering a broader range of sectors to analyse the impact of energy efficiency on firm performance. Future study could expand our study by using the mixed method with qualitative and quantitative to offer valuable insights on whether and how energy efficiency affects firm performance. Furthermore, studies could extend this research by comparing South Africa's context with other developing countries encountering same energy poverty to comprehensively understand how institutional, regional and market conditions explain ESG-firm performance nexus.

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Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of open access journals
TLA	Three letter acronym
LD	Linear dichroism

References

1. Adom, P. K.; Agradi, M.; Vezzulli, A. Energy efficiency-economic growth nexus: What is the role of income inequality? *J. Clean. Prod* ***2021***, *310*. https://doi.org/10.1016/j.jclepro.2021.127382
2. Akram, R.; Chen, F.; Khalid, F.; Irfan, M. Heterogeneous effects of energy efficiency and renewable energy on economic growth of BRICS countries: A fixed effect panel quantile regression analysis. *Energy* ***2021***, *215*. https://doi.org/10.1016/j.energy.2020.119019
3. Sarpong, F. A.; Wang, J.; Cobbinah, B. B.; Makwetta, J. J.; Chen, J. The drivers of energy improvement among nine selected West African Countries: A two-stage DEA method. *Energ, Strat. Rev* ***2022***, *43*. https://doi.org/10.1016/j.esr.2022.100910
4. Pavel, T.; Polina, S.; Liubov, N. The research of the impact of energy efficiency on mitigating greenhouse gas emissions at the national level. *Energ. Convers and Manag* ***2024***, 314. https://doi.org/10.1016/j.enconman.2024.118671
5. Dunlop, T. 2022. Energy efficiency: The evolution of a motherhood concept. *Soc Stud Sci* ***2022***, *52 (5)*, 710-732. https://doi.org/10.1177/03063127221096171
6. Chen, W.; Alharthi, M.; Zhang, J., Khan, I. The need for energy efficiency and economic prosperity in a sustainable environment. *G. Res* **2024**, *127*, 22-35. https://doi.org/10.1016/j.gr.2023.03.025
7. Herman, R.; Nistor, C.; Jula, N. M. The influence of the increase in energy prices on the profitability of companies in the European Union. *Sustainability 2023, 15 (21),* 1504. https://doi.org/10.3390/su152115404

 doi:10.20944/preprints202508.0745.v1

8. Naseer.; Hunjra, A. I.; Palma, A. Sustainable development goals and environmental performance: Exploring the contribution of governance, energy, and growth. *Res. Inter. Bus and Fin* **2025**, 73. https://doi.org/10.1016/j.ribaf.2024.102646
9. Jinapor, J. A.; Suleman, S.; Cromwell, R. S. Energy consumption and environmental quality in Africa: Does energy efficiency make any difference? Sustainability 2023, 15. https://doi.org/10.3390/su15032375
10. Garcia-Quevedo, J.; Jove-Llopis, E. Environmental policies and energy efficiency investments. An industry-level analysis. *Energ. Pol., 2021, 156*. https://doi.org/10.1016/j.enpol.2021.112461
11. Osorio-Aravena, J.C.; Aghahosseini, A.; Bogdanov, D.; Caldera, U.; Ghorbani, N.; Mensah, T. N.; Khalili, S.; Munoz-Ceron.; E.; Breyer, C. The impact of renewable energy and sector coupling on the pathway towards a sustainable energy system in Chile. *Renew. Sustain. Energy Rev., 2021,151.* https://doi.org/10.1016/j.rser.2021.111557
12. Dong, F.; Li, Y.; Goa, Y.; Zhu, J.; Qin, C.; Zhang, X. Energy transition and carbon neutrality: Exploring the non-linear impact of renewable energy development on carbon emission efficiency in developed countries. *Resour. Conservation Recycl* **2022**, *177*. https://doi.org/10.1016/j.resconrec.2021.106002
13. Lv, Y. Transitioning to sustainable energy: opportunities, challenges, and the potential of blockchain technology. *Front. Energ Res.,***2023**, *11*. https://doi.org/10.3389/fenrg.2023.1258044
14. Wang, H.; Ghasemi, M.; Ghadiri Nejad, M.; Khandan, A. Assessing the potential growth of Iran's hospitals with regard to the sustainable management medical tourism. *Health & Soc. Care Commun* **2023**, 1-12. https://doi.org/10.1155/2023/8734482
15. Tirkolaee, E. B.; Goli, A.; Mirjalili, S. Circular economy application in designing sustainable medical waste management systems. *Environ. Sci. Pollut. Res* **2022**, *29*, 90667-79668. https://doi.org/10.1007/s11356-022-20740-x
16. Dalla Valle, N.; Bertoldi, P. Promoting energy efficiency: Barriers, societal needs and policies. *Front. Energy Res* **2021**, *9*. https://doi.org/10.3389/fenrg.2021.804091
17. Gennitsaris, S.; Oliveira, M. C.; Vris, G.; Bafilios, A.; Ntinou, T.; Frutuoso, A. R.; Queiroga, C.; Giannatsis, J.; Sofianopoulou, S.; Dedoussis, V. Energy efficiency management in small and medium-sized enterprises: Current situation, case studies and best practices. *Sustainability* **2023**, *15(4)*, 3727. https://doi.org/10.3390/su15043727
18. Villanthenkodath, M. A.; Pal, S. Empowering tomorrow: Unleashing the role of technology driven energy efficiency for sustainable development in China. *J. Econ and Techn 2024, 2*. 155-165. https://doi.org/10.1016/j.ject.2024.02.001
19. Bergmann, A.; Rotzek, J. N.; Wetzel, M.; Gunther, E. Hang the low-hanging fruit even lower-Evidence that energy efficiency matter for corporate financial performance. *J. Clean. Prod* **2017**, *147. https://doi.org/10.1016/j.jclepro.2017.01.074*
20. Fan, L. T.; Pan, S.; Li, G.; Zhou, P. Does energy efficiency affect financial performance? Evidence from Chinese energy-intensive firms. *J. Clean. Prod* **2017**, *151*. https://doi.org/10.1016/j.jclepro.2017.03.044
21. Abbisa, L. T. Power outages, economic cost, and firm performance: Evidence from Ethiopia. *Util. Pol* **2018**, *53*.
22. Mintalbano, P.; Nenci, P. Energy efficiency, productivity and exporting: Firm-level evidence in Latin America. *Energ. Econ* **2019**, *79*.
23. Dybowski, M. Evaluation of energy efficiency impact on corporate financial performance in western Europe. Masters Dissertation, Utrecht University, Utrcht, Nethelands. **2023**. https://studenttheses.uu.nl/bitstream/handle/20.500.12932/45002/Dybowski%2C%20M._9105395.pdf?sequence=1&isAllowed=y (Accessed on 30 July 2025)
24. Wlodarczyk, A.; Szczepanska-Woszczyna, K.; Urbanski, M. Carbon and financial performance nexus of the heavily polluting companies in the context of resource management during COVID-10 period. *Resour. Pol* **2024**, *89*. https://doi.org/10.1016/j.resourpol.2023.104514
25. Moon, H.; Min, D. A DEA approach for evaluating the relationship between energy efficiency and financial performance for energy-intensive firm in Korea. *J. Clean. Prod* **2020**, *225*.

 doi:10.20944/preprints202508.0745.v1

26. Dopierala, L.; Mosionek-Schweda, M.; Laskowic, T.; ILczuk, D. Financial performance of renewable energy procedures: A panel data analysis from Baltic Sea Region. *Energ. Repo* ***2022***, *8*. 11492-11503. https://doi.org/10.1016/j.egyr.2022.09.009
27. Hulshof, D.; Mulder, M. The impact of renewable energy use on firm profit. *Energ. Econ* ***2020***, *92*. https://doi.org/10.1016/j.eneco.2020.104957
28. Liu, Z.; Zheng, H.; Gu, J.; Xu, S.; Ye, Y. Exploring the nexus between green finance and energy efficiency. *Heliyon* ***2024***, *10 (9)*. https://doi.org/10.1016/j.heliyon.2024.e30141
29. Yang, Y.; Gao, S.; Huang, H. Z. Sustainability agency theory: A new agency framework for social enterprises. *Sustainability* ***2025***, *17(11),* 4778. https://doi.org/10.3390/su17114778
30. Al-Faryan, M. A. Agency theory, corporate governance and corruption: An integrative literature review approach. *Cog. Soc. Scie* ***2020***. *10(1).* https://doi.org/10.1080/23311886.2024.2337893
31. Ongsakul, V.; Chatjuthamard, P.; Chintrakam, P.; Jiraporn, P.; Lee, S. M. Climate change, managerial ownership, and agency conflicts: Insights form the Paris Agreement. *J. Sustain. Fin & Invest* ***2025***, *15(2).* https://doi.org/10.1080/20430795.2025.2479554
32. Purnamasari, P;. Umiyati, I. Greenwashing and financial performance of firms: the moderating role of internal audit quality and digital technologies. *Coge. Busin & Manag* ***2024***, *11(1).* https://doi.org/10.1080/23311975.2024.2404236
33. Mohammed, K. S.; Serret, V.; Jabeur, S. B.; Nobanee, H. The role of artificial intelligence and fintech in promoting eco-friendly investments and non-greenwashing practices in the US market. *J. Environ. Manag****2024****, 359*. https://doi.org/10.1016/j.jenvman.2024.120977
34. Fan, Y.; Wang, R.; Alkaraan, F.; Wu, W. Decoding greenwashing practices toward sustainability: The synergistic influence of governance structure and policy-derive rhetorical strategies. *Energ. Econom* ***2025***, *148*. https://doi.org/10.1016/j.eneco.2025.108632
35. Schaltegger, S.; Horisch, J.; Freeman, R. Business cases for sustainability: A stakeholder theory perspective. *Organ & Environ* ***2019***, *32 (3).*
36. Mahajan, R.; Lim, W. M.; Sareen, M.; Kumar, S. Stakeholder theory. *J. Busin. Res* ***2023***, *166.* https://doi.org/10.1016/j.jbusres.2023.114104
37. Seroka-Stolka, O. Enhancing environmental sustainability: Stakeholder pressure and corporate Co2-related performance-An examination of the mediating and moderating effects of corporate decarbonisation strategies. *Sustainability* ***2023,*** *15(19),* https://doi.org/10.3390/su151914257
38. Baah, C.; Opoku-Agyeman, D.; Acquah, I. S. K.; Agyabeng-Mensah, Y.; Afum, Faibili, D.; Abdoulaye, F. A. M. Examining the correlation between stakeholder pressures, green production practices, firm reputation, environmental and financial performance: Evidence from manufacturing SMEs. *Sustan. Prod and Consum* ***2021***, *27*, 100-114.
39. Zhou, D.; Saeed, U. F.; Agyemang, A. O. Assessing the role of sustainable disclosure on firms; financial performance: Evidence from the energy sector of Belt and Road initiatives countries. *Sustainability* ***2024***, *16 (2),* 930. https://doi.org/10.3390/su16020930
40. Eitrem, A.; Meidell, A.; Modell, S. The use of institutional theory in social and environmental accounting research: a critical review. *Acc and Busin Res* ***2024,*** *54 (7),* 775-810. https://doi.org/10.1080/00014788.2024.2328934
41. Singhania, M.; Saini, N. Quantification of ESG regulations: A cross-country benchmarking analysis. Vision: *J. Busin Persp* ***2022***, *26 (2),* 163-171. https://doi.org/10.1177/0972262921105417
42. Handoyo, S.; Anas, S. The effects of environmental, social, and governance (ESG) on firm performance: The moderating role of country regulatory quality and government effectiveness in ASEAN. *Cogen. Busin & Manag* ***2024***, *11(1).* https://doi.org/10.1080/23311975.2024.2371071
43. Wu, Y.; Tham, J. The impact of environmental regulation, environmental, social and government performance, and technological innovation on enterprise resilience under a green recovery. *Heliyon* ***2023***, *9 (10).* https://doi.org/10.1016/j.heliyon.2023.e20278
44. Dzomonda, O; Fatoki, O. Environmental sustainability commitment and financial performance of firms listed on the Johannesburg Stock Exchange (JSE). *Intern. J. Environ Res and Pub. Heal* ***2020***, *17(20).* https://doi.org/10.3390/ijerph17207504

 doi:10.20944/preprints202508.0745.v1

45. Sitompul, H.; Saifi, M.; Hutahayan, B.; Sunarti, S. Use of renewable energy to enhance firm performance: A systematic review. *Sustainability* ***2024***, *16 (21),* 9157. https://doi.org/10.3390/su16219157
46. Boakye, D. J.; Tingbani, I.; Ahinful, G. S. The relationship between environmental management performance and financial performance of firms listed in the Alternative Investment Market (AIM) in UK. *J. Clean. Prod* ***2021***, 278. https://doi.org/10.1016/j.jclepro.2020.124034
47. Liu, R.; Song, F.; Wu, M.; Zhang, Y. Impact of corporate social responsibility on environmental investment: The mediating effects of information transmission and resource acquisition. *Sustainability* ***2024***, *16 (6),* 2457. https://doi.org/10.3390/su16062457
48. Herman, R.; Nistor, C.; Jula, N. M. The influence of the increase energy price on the profitability of companies in the European Union. *Sustainability* ***2023***, *15 (21),* 15404. https://doi.org/10.3390/su152115404
49. Stojceska, V.; Parker, N.; Tassou, S. A. Reducing GHG emissions and improving cost effectiveness via energy efficiency enhancement: A case study in a biscuit industry. *Sustainability* ***2022***, *14 (1),* 69. https://doi.org/10.3390/su14010069
50. Simionescu, L. N.; Gherghina, S. C.; Sheikha, Z.; Tawil, H. Does water, waste, and energy consumption influence firm performance? Panel data evidence from S &p 500 information technology sector. *Inter. J. Environ. Res and Publ. Heal* ***2020***, *71*.
51. Zhung, Z.; Ma, Y. The impact of energy consumption structure transformation on firms' total factor productivity: Evidence from China. Environ Sci Poll Res 2023, 76950-7668. https://doi.org/10.1007/s11356-023-27682-y
52. Ganda, F.; Olarewaju, O. The impact of water and energy performance on waste performance in South African JSE-listed companies. *Intern. J. Energ Res* ***2025***. https://doi.org/10.1155/er/9642568
53. Endrikat, J.; Guenther, E.; Hoppe, H. Making sense of conflicting empirical findings: A meta-analytic review of the relationship between corporate environmental and financial performance. *Uur. Manag. J* ***2014***, *32*, 735-751.
54. Friede, G.; Busch, T.; Bassen, A. ESG and financial performance: Aggregated evidence from more than 2000 empirical studies. *J. Sustain. Financ. Invest* ***2015,*** *5*, 2010-233.
55. Suttipun, M.; Duriyarattaka, S. The influence of energy management on Thai Manufacturing firm performance. *Manag. Res. Pract* ***2019***, *11,* 52-61.
56. Perez-Calderon, E.; Milanes-Montero.; Ortega-Rossel, F. J. Environmental performance and firm value: Evideince form Dow Jones Sustainability Index Europe. *Int. J. Environ. Res* ***2012,*** *6,* 1007-1014.
57. Lin, W. L.; Cheah, J. H.; Azali, M.; Ho, J. A.; Yip, N. Does firm size matter? Evidence on the impact of green innovation strategy on corporate financial performance in the automative sector. *J. Clean. Prod* ***2019***, *229*, 974-988.
58. Li, S.; Ngniatedema, T.; Chen, F. Understanding the impact of green initiatives and green performance on financial performance in the US. *Bus. Stra. Environ* ***2017,*** *26*, 776-790.
59. Lakkanawanit, P.; Dungtripop, W.; Suttipun, M.; Madi, H. Energy conservation and firm performance in Thailand: Comparison between energy efficiency-intensive and non-energy-intensive industries. *Energies* ***2022***, *15,* 7532. https://doi.org/10.3390/en15207532
60. Al Mahi, M. Gaining more from energy efficiency: The role of firms' environmental concerns. *J. Environ. Manag* ***2025***, *373*.
61. Chlyeh, D. The impact of renewable energy performance on corporate financial performance. Master's Thesis. Ibn Haldun Universitesi. Lisansustu Egitim Enstitusu, Basaksehir, Turkey 2020.
62. Ruggiero, S.; Lehkonene, H. Renewable energy growth and the financial performance of electric utilities: A panel data study. *J. Clean. Prod* ***2017***, *142 (4*). https://doi.org/10.1016/j.jclepro.2016.10.100
63. Marti-Ballester, C. P. Sustainable energy systems and company performance: Does the implementation of sustainable energy improves company's financial performance? *J. Clean. Prod* ***2017***, *162.* https://doi.org/10.1016/j.jclepro.2016.12.015
64. Basturk, M. F. Does green finance reduce carbon emissions? Global evidence based on system generalised method of moments. *Sustainability* ***2024***, *16 (18),* 8210. https://doi.org/10.3390/su16188210

65. Lundell, R.; Bond, S.; Windmeijer, F. Estimation in dynamic panel data models: Improving on the performance of the standard GMM estimator. In Nonstationary Panels, Panel Cointegration, and Dynamic panel; Emerald Publishing Limited: Leeds, UK, 2001; pp. 53-91.
66. Fu, T.; Li, J. An empirical analysis of the impact of ESG on financial performance: the moderating role of digital transformation. *Front. Environ. Sci* ***2023***,*11*. https://doi.org/10.3389/fenvs.2023.1256052
67. Ahmad, N.; Mobarek, A.; Roni, N. N. Revisiting the impact of ESG on financial performance of FTS350 UK firms: Static and dynamic data analysis. *Cog. Bus & Manag* ***2021***, *8*.
68. Chen, Z.; Xie, G. ESG disclosure and financial performance: Moderating role of ESG investors. *Intern. Revi. Financ. Anal* ***2022***, *83.*
69. Masongweni, V.; Simo-Kengne, B. D. The impact of sustainable investment on firm performance in South Africa. *South African Journal of Accounting Research, 38 (2).* https://doi.org/10.1080/10291954.2024.2306701
70. Issa, A.; Hanayska, R. Powering profits: How renewable energy boosts financial performance in European non-financial companies. *Intern. Acc & Inform. Manag* ***2023***, *31 (4).*
71. MSCI Rating Methodology. MSCI Provisional ESG Ratings Methodology. MSCI ESG Research LLC 2024. https://www.msci.com/esg-and-climate-methodologies (Accessed on 25 July 2025).
72. Zhou, J.; Sharpe, W. H.; Halabi, A. K. Unlocking your firm value with ESG performance? Evidence from ASX-Listed companies. *J. Risk. Financ. Manag* ***2025***, *18 (5*), 247. https://doi.org/10.3390/jrfm18050247
73. Bolibok, P. M. Does firm size matter for ESG risk? Cross-sectional evidence from the banking industry. *Sustainability* ***2024***, *16 (2), 679*. https://doi.org/10.3390/su16020679
74. Gregory, R. P. The influence of firm size on ESG score controlling for ratings agency and industry sector. *J. Sustain. Financ. Invest* ***2022***, *14*, 86-99.
75. Aydogmus, M.; Gulay, G; Ergun, K. Impact of ESG performance on firm value an profitability. *Bor. Istan. Rev* ***2022***, *22.* https://doi.org/10.1016/j.bir.2022.11.006
76. Li, Q.; Tang, W.; Li, Z. ESG systems and financial performance in industries with significant impact: A comprehensive analysis. *Front. Sustain* ***2024***, *5.* https://doi.org/10.3389/frsus.2024.1454822
77. Chininga, E.; Alhassan, A. L.; Zeka, B. ESG ratings and corporate financial performance in South Africa. *J. Accoun. Emerg. Econ* ***2023***, *14 (3).* https://doi.org/10.1108/JAEE-03-2023-0072
78. Shobhwani, K.; Lodha, S. Impact of ESG disclosure scores on financial, operating and market-based performance: Evidence from NSE-100 companies. *MNIMS Manag. Rev* ***2024***, *32 (3).* https://doi.org/10.1177/09711023241306219
79. Setyaningsih, W.; Wibowo, R. S. Does earnings per share contribute to the effect of ESG score on share price of mining sector? *Advan. Account. Innov* ***2024***, *1(1).* https://doi.org/10.69725/aai.v1i1.90
80. Wu, S.; Du, X.; Li, Z. The impact of ESG performance on firm value: The moderating role of ownership structure. *Sustainability* ***2022***, *14 (21),* 15507. https://doi.org/10.3390/su142114507
81. Atan, R.; Alam, M.; Zamri, M. The impact of environmental, social and governance factors on firm performance: Panel study of Malaysian companies. *Manag. Environ. Qual* ***2018***, *29 (2).*
82. Hamdi, K.; Guenich, H.; Saada, M. Does corporate governance performance promote ESG: Evidence from US firms. *Cogen. Busin & Manag* ***2022***, *9(1).* https://doi.org/10.1080/23311975.2022.2154053
83. Pastor, M.; Stambaugh, R. F.; Taylor, L. A. Dissecting green returns. NBER Working Paper No. 28940. *J. Finan. Econ* ***2022***, *146*.
84. Bamel, N.; Khatri, K.; Bamel, U.; Kumar, S. ESG disclosure and firm performance in global south economy: Does industry profile and board independence moderate the relationship. *Intern. Rev. Econo & Fin* ***2025***, *100*. https://doi.org/10.1016/j.iref.2025.104093