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WAVELET ANALYSIS OF TIME-SCALE DYNAMICS BETWEEN NIFTY ENERGY AND ESG RETURNS

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ABSTRACT
This study investigates the time-scale dependence between the Nifty Energy Index and the Nifty ESG Index using wavelet analysis, utilizing daily return data from December 30, 2016, to February 7, 2025, we apply Wavelet Coherence Analysis (WTC) to examine co-movement patterns across different investment horizons. The findings reveal that the correlation between energy and ESG investments varies over time, with the strongest coherence observed at 8-day and 64-day intervals, short-term market reactions and medium-term financial trends. While ESG and energy indices exhibit moderate long-term alignment. The study contributes to sustainable finance literature by demonstrating how wavelet-based techniques can enhance understanding of ESG-Energy interactions, offering valuable implications for investors, policymakers, and portfolio managers seeking to optimize ESG-integrated investment strategies.
KEYWORDS: *Wavelet Coherence Analysis, Time-Scale Dependence, ESG Investing.*

INTRODUCTION
Environmental, Social, and Governance (ESG) investing has gained significant traction in India, driven by regulatory developments and investor awareness (Maji & Lohia, 2024). Research indicates that ESG investing not only promotes sustainable business practices but also enhances financial performance, with firms disclosing higher ESG scores attracting more institutional investors (Chaklader et al., 2024). Additionally, ESG-focused portfolios demonstrated resilience during financial downturns, such as the COVID-19 pandemic (Sood et al., 2022). Indian investors, especially retail investors, are increasingly considering ESG factors, with socially responsible investors showing greater awareness and preference for ethical investment choices (Jonwall et al., 2022). Furthermore, foreign institutional investors are favouring firms with strong ESG commitments, emphasizing the global appeal of ESG investments in India (Chauhan & Kumar, 2019). The energy sector plays a pivotal role in financial markets due to its impact on economic growth, employment, and capital markets (Behl et al., 2021). In India, energy firms with high ESG performance exhibit better long-term financial sustainability, attracting investors focused on sustainable returns. However, the bidirectional relationship between ESG and firm value varies across industries, with the energy sector showing a lag effect in realizing financial benefits from ESG investments (Behl et al., 2021). Studies also suggest that ESG factors influence financial flexibility, with energy firms leveraging ESG investments to improve credit access and risk management (Zhang & Liu, 2022). Additionally, energy companies that integrate ESG practices experience enhanced innovation and long-term financial stability (Ren & Cheng, 2024). Time-scale dependence is crucial in ESG investing as its impact on financial performance is dynamic and varies across different investment horizons (Gubareva et al., 2023). Short-term ESG investments may not yield immediate financial returns, but long-term commitment often results in enhanced risk-adjusted returns (Aich et al., 2021). Furthermore, ESG-related stock returns and risk assessments show non-linear patterns, requiring investors to adopt a multi-time-frame approach (Ersoy et al., 2022). Investment strategies that consider long-term ESG trends outperform short-term speculative approaches, emphasizing the need for sustainable investment horizons (Fu & Li, 2023). Understanding time-scale dependence also helps investors optimize portfolio performance by aligning ESG investments with appropriate risk levels and market cycles (Garrido-Merchán et al., 2023). Thus, ESG investing, particularly in India's energy sector, demands a long-term perspective, strategic adaptation, and an understanding of time-scale dependencies for maximizing financial and societal benefits.

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LITERATURE REVIEW

The role of ESG (Environmental, Social, and Governance) indices has become prominent in modern investing as investors increasingly recognize their value in risk management and portfolio diversification. ESG indices offer a viable strategy to improve portfolio performance while ensuring socially responsible investments (Liu & Hamori, 2020). ESG scores, when integrated with traditional investment fundamentals, can influence stock performance positively under certain conditions (Sorensen et al., 2022). Furthermore, passive ESG investing strategies are seen as a cost-effective way to manage systematic ESG risk by following ESG-screened indices, which show reduced beta coefficients and improved risk-adjusted returns (Jin, 2022). Despite the potential benefits, ESG ratings exhibit inconsistencies across data providers, leading to challenges in standardizing ESG performance evaluations (Gyönyörová et al., 2021). Additionally, while ESG funds tend to support environmentally and socially positive shareholder proposals, their overall financial performance may vary (Dikolli et al., 2021). The energy sector's connection with financial markets has deepened through financialization, where energy prices reflect market behaviours rather than purely supply-demand fundamentals. This phenomenon introduces volatility and systemic risks, especially during external shocks like financial crises (Ji et al., 2019). Moreover, financial sector development plays a pivotal role in driving renewable energy investments, especially in countries with mature financial markets (Kim & Park, 2016). Energy markets are increasingly treated like commodity markets, where spot pricing, futures trading, and financial derivatives have become common strategies for risk management (Berrie & Hoyle, 1985). Additionally, systemic risk studies indicate that financial linkages within the energy sector have significant implications for overall economic stability, especially when considering cross-market contagion effects (Kerste et al., 2015). Traditional methods such as correlation and regression have limitations in detecting non-stationary relationships in financial markets. Wavelet analysis has emerged as a superior alternative, providing localized insights into financial data trends. By decomposing financial time series into various frequency components, wavelet analysis effectively identifies structural changes and patterns that traditional methods overlook (Ramsey et al., 1995). Wavelet techniques enable a detailed understanding of volatility clustering and market cycles, especially when combined with other approaches like Fourier transforms (Grigoryan, 2005). Compared to Fourier transforms, wavelet analysis provides superior time-frequency resolution, making it highly effective in identifying dynamic market shocks and detecting long-term investment cycles (Strang, 1993). The hybridization of wavelet and Fourier methods further enhances spectral analysis, improving accuracy in complex market environments (Tarasiuk, 2004). Wavelet coherence provides a time-frequency map that shows how two signals are correlated over time and across different frequency bands. It is a normalized measure of dependence, allowing for the construction of confidence intervals and is often considered more interpretable than the wavelet cross-spectrum (Jérémie Bigot et al., 2011).

METHODOLOGY

This study employs a quantitative research approach to examine the time-scale dependence between the NIFTY Energy and NIFTY ESG indices. It is an empirical study based on secondary data, utilizing statistical and wavelet-based techniques to analyse the relationship between the two indices over different time horizons. The dataset consists of daily return data of the NIFTY Energy Index and the NIFTY ESG Index, covering the period from December 30, 2016, to February 7, 2025. The data is sourced from the National Stock Exchange (NSE) website. The sample includes 2,010 observations for each index, ensuring a robust analysis of their performance and interdependence. The study aims to answer, how the NIFTY Energy and NIFTY ESG indices co-move across different time scales using R software, leveraging packages such as Wavelet Comp for wavelet coherence analysis.

DATA ANALYSIS & INTERPRETATION

Before applying wavelet-based techniques, we conduct a descriptive statistical analysis of the daily returns of the NIFTY Energy and NIFTY ESG indices.

Table – 1 (Descriptive Statistics)

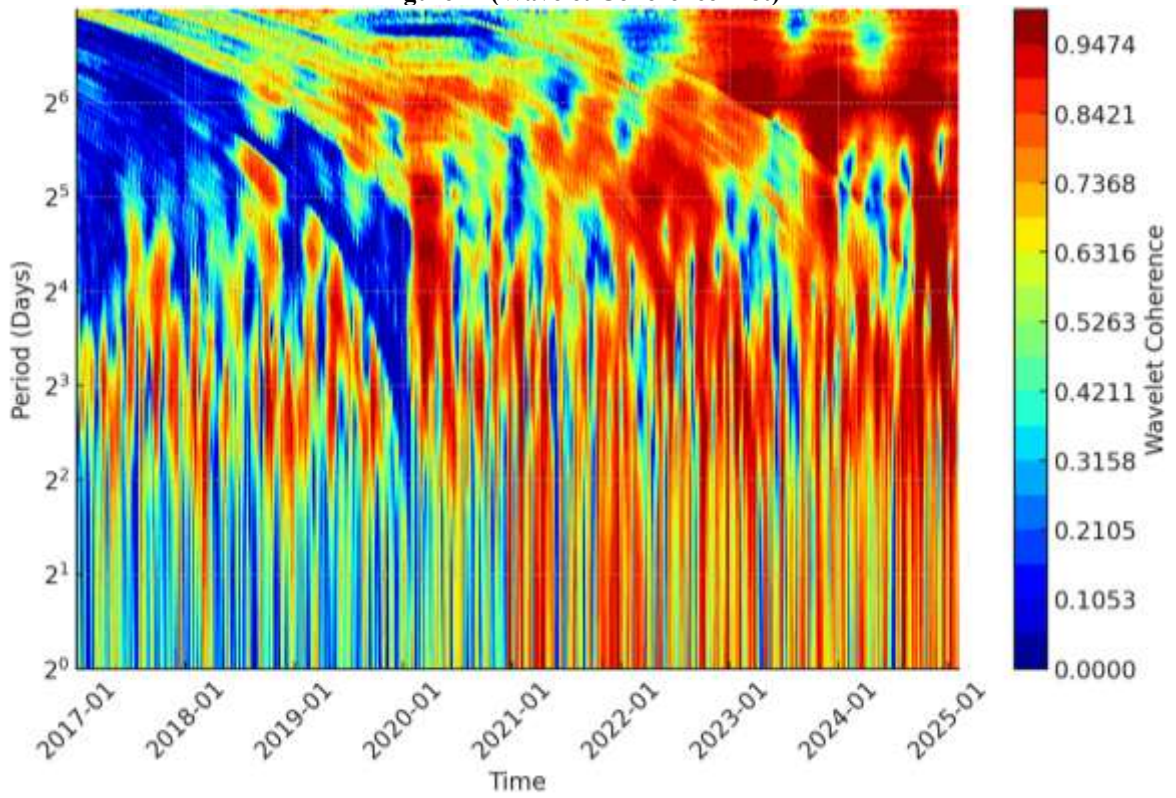
Statistic	Energy	ESG
Count	2010	2010
Mean	0.07%	0.06%
Std Dev	1.36%	1.04%
Min	-12.47%	-12.58%
Median	0.12%	0.11%
Max	8.63%	9.09%

The descriptive statistics of NIFTY Energy and NIFTY ESG daily returns reveal key insights into their distribution and volatility. Both indices exhibit a small positive mean return (0.0007 for Energy and 0.0006 for ESG), indicating slight upward trends over time. The standard deviation values (0.0136 for Energy and 0.0104 for ESG)

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suggest that NIFTY Energy is more volatile than NIFTY ESG. The minimum and maximum returns highlight extreme market fluctuations, with Energy experiencing a maximum drop of -12.47% and a peak of 8.63%, while ESG faced a sharper decline of -12.58% and the highest gain of 9.09%. The median values (0.0012 for Energy and 0.0011 for ESG) suggest that both indices have a slight positive skew. The interquartile range (between the 25th and 75th percentiles) indicates that most returns cluster within a narrow range, reflecting periods of relative stability interspersed with occasional high volatility**.** To examine the time-scale dependence between NIFTY Energy and NIFTY ESG returns, we apply Wavelet Coherence Analysis (WTC). The WTC plot provides a visual representation of how the two indices move together over different time scales.

Figure -1 (Wavelet Coherence Plot)



The Wavelet Coherence Analysis (WTC) reveals the time-scale dependence between NIFTY Energy and NIFTY ESG returns, highlighting the strength and variability of their relationship over different horizons. The coherence values indicate periodic co-movement, with notable fluctuations across short-, medium-, and long-term time frames. Areas with high coherence (closer to 1) indicate strong correlation at time scales, while low coherence suggests weak or no relationship. Significant regions, highlighted in the wavelet coherence plot, are further analysed to determine if the relationship is consistent or varies over time.

Table -2 (Wavelet Coherence Summary Table)

Period (Days)	Average Coherence
4	0.540
8	0.635
16	0.529
32	0.526
64	0.644
128	0.556

In the short term (4–16 days), the average coherence ranges from 0.529 to 0.635, signifying a moderate correlation between the indices. The peak coherence at the 8-day scale (0.635) suggests that NIFTY Energy and ESG exhibit the strongest synchronization around the weekly cycle, possibly reflecting short-term market dynamics, investor sentiment, or regulatory announcements affecting both sectors. Moving to the medium-term horizon (32–64 days), coherence values remain relatively stable between 0.526 and 0.644, indicating a persistent relationship between the indices over a few months. The highest coherence at 64 days (0.644) suggests that the indices align more significantly at a 2–3-month interval, likely influenced by quarterly financial reports, sectoral performance trends,

or macroeconomic factors impacting energy and ESG investments. Over the long term (128 days), coherence remains moderate (0.556), signifying that while NIFTY Energy and ESG returns exhibit a degree of long-run association, the relationship is not perfectly stable. This suggests that external forces such as policy changes, shifts in global energy markets, or evolving ESG investment strategies may introduce variability in their co-movement over extended periods. Notably, the strongest coherence is observed at the 8-day and 64-day time scales, emphasizing key periods of heightened synchronization between the indices.

FINDINGS

The study reveals that the relationship between the NIFTY Energy Index and the NIFTY ESG Index varies across different time scales. In the short term (4–16 days), coherence values between 0.529 and 0.635 indicate a moderate correlation, likely influenced by market sentiment and regulatory announcements. The highest coherence at the 8-day scale (0.635) suggests that short-term ESG and energy investments are sensitive to sudden market reactions. In the medium term (32–64 days), coherence stabilizes between 0.526 and 0.644, with the strongest correlation at 64 days (0.644), likely influenced by quarterly earnings, macroeconomic trends, and ESG policies. This highlights the importance of medium-term trends in sustainable investing. In the long term (128 days), coherence remains moderate at 0.556, indicating that external factors like policy shifts and global energy market trends introduce variability. These findings suggest that ESG-aligned energy investments require a flexible and dynamic approach due to their evolving co-movement.

CONCLUSION

The study underscores the time-scale dependence of ESG and energy index performance, with short-term movements influenced by market sentiment, medium-term by financial cycles, and long-term by structural trends and policies. The strongest coherence at the 8-day and 64-day scales suggests key synchronization points for investment optimization. For investors, short-term strategies should consider market volatility, medium-term strategies should align with financial cycles, and long-term strategies must factor in policy uncertainties. The findings highlight the need for a multi-time-frame approach in portfolio management, contributing to sustainable investing literature. Future research could explore the impact of global sustainability policies and climate risks on ESG-energy relationships.

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