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ENERGY MARKET DYNAMICS AND EMERGING EQUITY MARKETS: INSIGHTS FROM A WAVELET-BASED TIME–FREQUENCY ANALYSIS

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Abstract
This study explores the dynamic relationship between clean energy stocks and equity markets across three major regions APAC**,** EMEA, and the Americasusing wavelet coherenceanalysis over the period 2015–2024. By examining five major global crises Oil Crisis, Climate Crisis, COVID-19 pandemic, Russia–Ukraine War, and Israel–Hamas conflict the research uncovers how market interactions evolve across both time and frequency domains. The findings reveal region-specific patterns: equity markets in the APAC region, such as India, Taiwan, and Indonesia, demonstrate strong coherence with clean energy, particularly during pandemic and geopolitical shocks. EMEA markets, especially oil-dependent economies, exhibit heightened sensitivity during energy disruptions, while certain European markets show signs of increasing decoupling driven by diversification into sustainable assets. In the Americas**,** markets like Brazil and Mexico remain volatile due to energy dependency, whereas mineral-rich nations like Chile and Peru show more stable interactions with clean energy. Descriptive statistics confirm the presence of high volatility, non-normal distributions, and persistent asymmetries, reinforcing the use of non-linear modeling techniques. The study concludes that clean energy not only reflects environmental considerations but also plays a strategic financial role, offering predictive insights and risk mitigation across emerging markets during periods of systemic uncertainty.

Key words: APAC, EMEA, Americas, wavelet coherence, crisis

1.Introduction

Emerging economies are at a crossroad in the process of shifting to clean energy(Khosla et al., 2020). The sustainability and stability of both economies and the environment are increasingly at risk due to rising emissions, which have drastically altered global energy and financial dynamic (Gupta & Katoch, 2024).The growing interconnectedness of global markets has accelerated economic globalization, especially following recent financial crises that have introduced heightened volatility in stock markets. These disruptions impede the smooth functioning of financial systems, intensifying uncertainty and investment risk. Consequently, forecasting market dynamics has become an essential area of financial research, with implications for asset valuation and strategic portfolio allocation (Gupta, 2023).

Although the rest of the world has improved renewable sources, such as solar and wind, to the extent that costs have decreased by a large margin and efficiency has improved greatly, transition expenditure on energy in young economies has been low in emerging economies(Babayomi et al., 2022). The document analyzes the capacity of emerging markets to realize their potential in clean energy, commissioned by the Climate Investment Funds (CIF) by Bloomberg NEF and outlines the obstacles to allowing this. Five key technologies, namely solar, on- and offshore wind, batteries, and clean hydrogen, are on the center of attention that requires specific measures helping to reduce costs, ramp up the infrastructure construction process, and establish an enabling environment to deploy them. Although clean energy technologies have become much cheaper, several emerging economies cannot afford clean energy solutions due to issues concerning financing, policy, and regulations, which

prevent mass investing(Carpejani et al., 2019). Still, these are the markets with the greatest potentially growth in clean energy, and, with the help of localizing the deployment of mature technologies and a shift to eliminate carbon-intensive activities, they may contribute to the decarbonization effort of the whole world. Programs to support clean hydrogen and accelerate the transition away from coal also must be part of making the energy transitions in these countries. As the report points out, once the required capital is unlocked and the appropriate environment to favour these emerging technologies is created, the exciting markets will not only be able to fulfill their climate and energy ambitions, but they would also play a major role in clean energy transformation within the global mix.

The growth of emerging markets is advancing clean energy investment, with a rise of the total energy system investment that was at $2.2 trillion in the year 2023, an increment of 35 percent as of 2020. Yet, it is mainly contributed by China alone reaching an amount of 1.1 trillion. Other emerging markets are at a disadvantage of not investing in energy system as well as in low-carbon solutions. The financing gap in achieving world climate goals is huge where emerging markets, not China, require an investment of 69 trillion trying to be in the net legal area in 2050. The global average of these markets is estimated as a percentage of $4.3 trillion per year to reach the targets of the Paris Agreement, and investments should include a great deal of clean technologies like renewable energy, electric vehicles, and energy storage. What makes the job especially difficult is that in 2023, all new-build clean energy investment was focused on just 15 emerging markets where an amazing 84 percent was being spent[1]. However, such countries as India, Kenya, Nigeria, and Namibia are experiencing notable improvement and thanks to that, Kenya has elevated its position in clean energy investment rankings by 15 points. By the middle of 2024, clean energy goals were in place in 95 percent of emerging markets and clean power investments in these markets were over 100 billion dollars, first time. Although the gap has been reduced further, the difference is still high, as most of the emerging markets are still recording a wide gap between satisfaction in clean energy goals.

The results of the study reveal that clean energy markets act as leading indicators for equity markets in several emerging economies, particularly during major global crises. Wavelet coherence analysis confirms that this leadership role varies across time horizons short-, medium-, and long-term and differs by region. EMEA markets such as Egypt, Saudi Arabia, and Poland show strong short-term coherence during oil and geopolitical shocks, while APAC markets including India, Taiwan, and Indonesia display significant coherence during the pandemic and climate-related phases. In the Americas, Brazil and Mexico exhibit volatility due to energy dependencies, whereas Chile and Peru demonstrate stable coherence patterns due to their resource-based economies. These findings suggest clean energy plays a dual role as a sustainable investment avenue and as a strategic risk indicator during periods of economic and geopolitical uncertainty.

This paper aims to investigate the dynamic time-frequency relationship between clean energy indices and emerging equity markets across the APAC, EMEA, and Americas regions using wavelet coherence analysis. The study focuses on five major crisis periods from 2016 to 2024 to assess how clean energy interacts with national stock markets during different global shocks. The rest of the paper is structured as follows: Section 2 provides a review of the existing literature, Section 3 outlines the methodology including the wavelet-based approach,

[1]https://about.bnef.com/insights/clean-energy/emerging-markets-make-headway-on-clean-energy-policy-and-investment-but-trillions-more-needed-for-net-zero-bloombergnef-reveals/

Section 4 presents descriptive and wavelet-based empirical findings, and Section 5 concludes with policy implications and future research directions.

2. Literature Review

The dysfunctional interaction between clean energy markets and stock markets has attracted a lot of attention, especially with the concerns over the manner of volatility and risk spillover behaving on the various markets and the various sectors. Combined with the fact that the green energy industry has become increasingly important, these spillovers have become more and more relevant due to the changing nature of global financial markets. With the uncertainty in the global economy that is mainly experienced whenever there is a crisis, it is imperative to learn how clean energy is linked to markets in the financial sector to diversify portfolio and manage risk.

Other literatures such as those of Khalfaoui, Jabeur, et al. (2022) and K. Yang et al. (2025) enlighten the spillovers between clean stock markets and the traditional stock markets, particularly during the extreme market regime. Khalfaoui, Mefteh-Wali, et al. (2022) made use of spillover network analysis to disclose the influence of climate risk and clean energy spillovers on the stock markets in the United States. This study suggests that clean energy markets and climate policy have been used as important conduit of shocks especially during boom states and bust with the relevance in extreme market conditions. Along those lines, Y. Yang et al. (2025) adopt a quantile procedure to investigate the spill overs between renewable energy tokens and energy asset amidst volatile regimes like the COVID-19 pandemic and geopolitical strains. They discover that the clean energy markets take control of the markets dominated by fossil fuel in the case of extremes, and as a result, learn about the market dynamics under a state of crisis.

Another area of interest is the role of uncertainty in shaping market forces such as the one analysed by Fasanya and Oyewole (2023) who study the effects of uncertainty of infectious disease on the connection between African stock markets and clean energy stocks. A higher level of uncertainties related to pandemic has been noted to determine the dynamics between the two markets especially at lower and median quantiles, which has been found to be a non-linear causing relationship. In the same vein, Jia et al. (2023) study the spillover of risks across the prices of clean energy stocks during various stages of the COVID-19 crisis, discovering that volatility was increasing at the beginning of the pandemic outbreak but returned closer to normal during the recovery period, which illustrates the inherent role of crisis in defining the interconnectedness of clean energy markets and stocks.

Moreover, such publications as Ren and Lucey (2022) or Li and Zhong (2025) concern the correlation between clean energy markets and cryptocurrency markets, furthering the spillover literature. Accordingly, Ren and Lucey (2022) imply that the clean energy markets are not used as a direct hedge to cryptocurrencies, and they serve as a weak safe haven, especially when cryptocurrencies display a high energy expenditure when bearish markets are used. This observation is to supplement the interest that is increasing on sustainable financial instruments as investors pursue a portfolio-based diversification strategy.

Another important area of concern is the correlation or lack thereof between clean energy markets and green financial assets including green bonds. Our study will look at the volatility spillovers between the green bond market and the renewable energy stocks, and it is based on the fact that there exists a unidirectional volatility spill over between the renewable energy stock price and the green bond price Gyamerah et al. (2022). This indicates that investors in the green bond market must look at the position of renewable energy stocks since both markets are intertwined.

Conversely,(Li & Zhong, 2025), investigate asymmetric effects between the spillover of clean energy markets and that of the industrial stock markets reflecting that clean energy submarket markets are net receivers of risk whereas industrial stock submarkets are transmitters of risk. In their research paper, it is evident that the necessity to examine the time-varying and asymmetric nature of spillovers is a priority especially during some extreme market conditions like crisis or important policy change. The authors also note that these spillover dynamics may be largely changed due to the external uncertainty, including economic policy uncertainty and climate policy uncertainty.

The spillover effects are higher in case of crisis like Global Financial Crisis (GFC), oil crisis or the COVID-19 pandemic. Research works such as the one conducted by Umar et al. (2022) and Karim et al. (2022) emphasize the fact that any volatility in the market during such crises can cause increased volatility spillovers between clean energy markets and fossil fuel markets. According to Umar et al. (2022), clean energy markets have been found to be more erratic during the COVID-19 pandemic than at other times and the volatility spillover has been higher in the short term. In a similar manner, Karim et al. (2022) report high Clean energy spillovers into regional stock markets, especially during the Global Financial Crisis, Shale Oil Crisis, and COVID-19 crises.

Indeed, such studies as the ones by Deng et al. (2023) and Karkowska and Urjasz (2024) explore how geopolitical crises, in the form of the Russia-Ukraine conflict, impact the interrelatedness between the clean energy and traditional energy markets. Their results indicate that risk contagion between clean energy and non-ferrous metal markets grew during the COVID-19 period, which is an indication of greater interconnectedness between the markets due to the crisis (Deng et al., 2023). Karkowska and Urjasz (2023) also investigate the volatility spillovers in the context of the Russia Ukraine conflict and discover that clean energy markets are less risky than global equity markets and thus represent valuable investment opportunities when geopolitical risk is increasing.

Even though these studies are useful in going through, there are still gaps in their literature that should be filled. The spillover effects of the research are relatively done in the developed markets and there is no heavy literature regarding the empirical research on spillover effects of emerging markets and the concept of clean energy. The literature has also failed to present detailed works that specifically investigate various aspects of dynamic relationships between the emerging market stock markets and clean energy markets with special interest on the areas like Asia-Pacific (APAC), Europe, Middle East, and Africa (EMEA) to that of the Americas.

These gaps are addressed in my research since I employ the use of wavelet analysis to explain the time frequency aspects of the spillover between the stock markets of emerging markets and clean energy. This study can help enhance the knowledge on the spillover dynamics to emerging economies in the APAC, EMEA, and Americas. This will give important information on the co-movements that exist between the stock markets of these regions and clean energy especially when there are economic, geopolitical and environmental crisis that is taking place. The wavelet analysis can be used to analyze the profound effects of the spillover at different points of time giving a better insight on how the emerging markets work with the clean energy in various market environments. The research will have significant implications to investors and policymakers, as well as other stakeholders who need to cut through the complexities of the current energy transition in the emerging economies.

3. Data and Research Methodology

3.1 Data

The data employed in the research paper seeks to examine the correlation between equity market in the emerging markets and two energy markets, in the case in the emerging markets through MSCI Emerging Markets Indexes. MSCI Emerging Markets Indexes are designed to represent the development of the rapidly emerging economies of the world and present a comprehensive tool to analyze in the emerging regions. So far more than a trillion dollars of assets are tracked to these indexes, and they are used to learn the financial performance and pattern of the emerging markets(EM). We retrieved the statistics of 2015-2024 and represented the countries of various regions: EMEA (Czech Republic, Hungary, Kuwait, Qatar, Saudi Arabia, Poland, UAE, Egypt, Greece, South Africa, and Turkey)(see Fig.1), APAC (Philippines, Indonesia, and Thailand, South Korea, China, Malaysia, India, and Taiwan)(see Fig 2) and The Americas (Chile, Mexico, Peru, Brazil, and Colombia)(see Fig.3). Furthermore, the research also provides the details on clean energy and fossil market that includes such variables as S&P Global Clean Energy Transition Index, S&P GSCI Natural Gas, S&P GSCI Crude Oil and S&P GSCI Heating Oil. The entire information was received on Bloomberg that is a high quality and informative database to be discussed. This information provided has proven a sound ground to understand the relationship between returns on equity in the emerging market and clean energy industry and the gain of the fossil fuel industry.

The countries have been grouped under MSCI Emerging Markets Indexes, as table1 indicates. Using this table, the countries that were analyzed and the regions, which they belong to, may be seen as an overview, serving the purpose of comparing the dynamics of equity and energy market in different emerging economies and the energy markets in general clearer. The data set is a healthy foundation of a study regarding the correlation between the returns of equity in the emerging markets with clean energy and fossil fuel sectors.

Table 1 Classification of Emerging Markets and Energy Markets

Region	Markets	Energy Market
EMEA	Czech Republic (PX), Hungary (BUX), Kuwait (BKP), Qatar (QSI), Saudi Arabia (TASI), Poland (WIG20), UAE (FTFADGI), Egypt (EGX30), Greece (ATG), South Africa (FTSE/JSE), Turkey (MITR00000PTR)	Clean Energy (SPGTCLEN)
APAC	Philippines (PSEi), Indonesia (IDX), Thailand (SETI), South Korea (KS11), Malaysia (FBMKLCI), Taiwan (TWII), China (SSE), India (NIFTY 50)	
AMERICAS	Chile (SPIPSA), Mexico (MXN), Peru (SPBLPGPT), Brazil (IBOV), Colombia (COLCAP)	

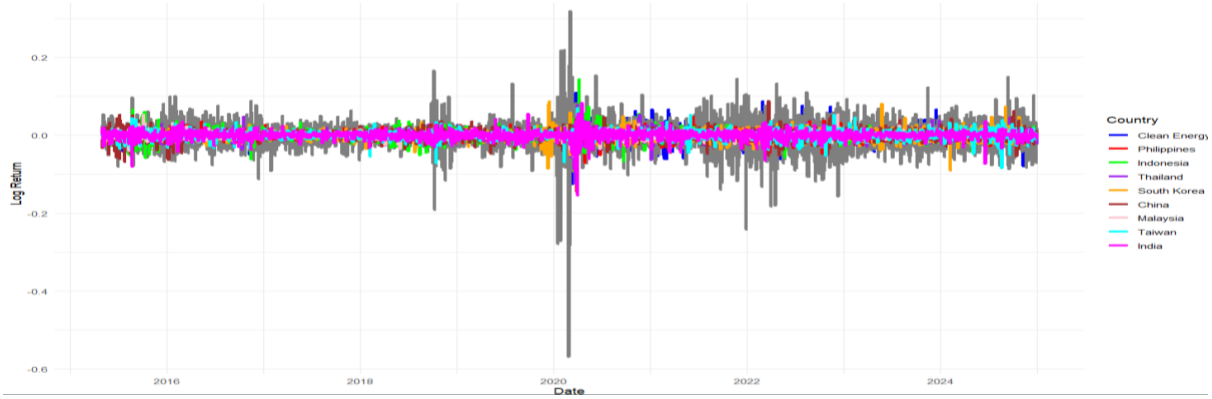


Fig1: Return plot of Clean Energy and APAC Economies Stocks

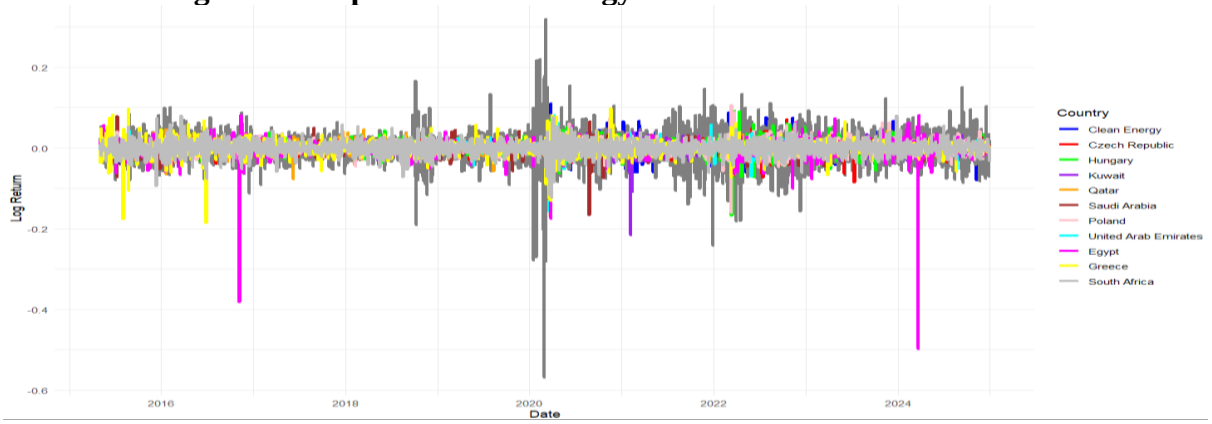


Fig2: Return plot of Clean Energy and EMEA Economies Stocks

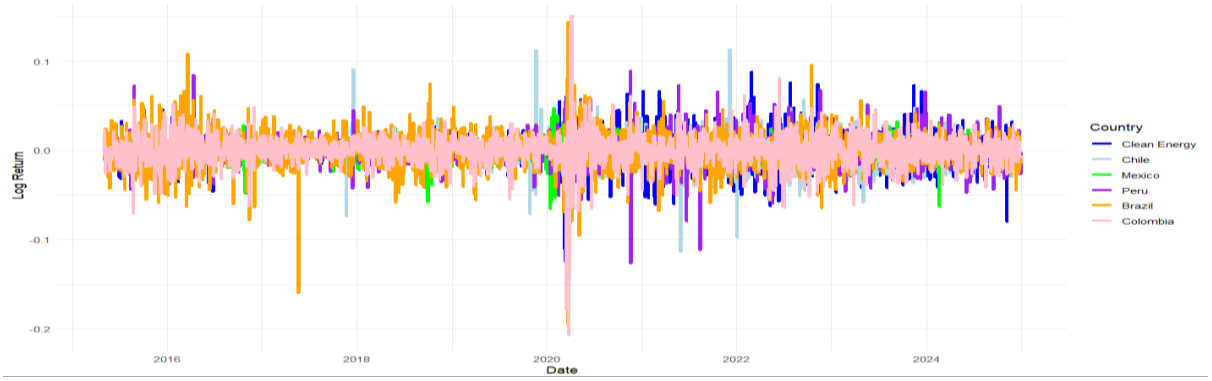


Fig3: Return plot of Clean Energy and Americas Economies Stocks

Fig 1 explains the volatility in APAC economies and clean energy stocks of the period between 2016 to 2024. The oil crisis of 2016 led to drastic losses in such countries as China, India, and South Korea. Nevertheless, due to the increasing investments in clean energy in 2017, such economies as China or India became more stable, with Indonesia and the Philippines being the most volatile. The volatility was so pronounced during the COVID-19 pandemic particularly in Indonesia and the Philippines. Green recovery efforts found their way in clean energy stocks which were more resilient at this period. The Russia-Ukraine war that occurred in 2022-2023 destabilized the energy markets with Taiwan and South Korea being volatile.Until 2024 clean energy stocks are experiencing growth despite some volatility caused by the Israeli-Hamas conflict.

In this Fig 2 2016-2024 the volatility of the EMEA region is highlighted. The 2016 oil crisis caused significant swings among oil-centered economies such as the Saudi Arabia, Kuwait, and Qatar. Still, such European economies as Poland and Greece are considered more stable because of increased investments in clean energy. In 2020, there was a lot of volatility in the market due to covid-19 especially in South Africa. Nevertheless, other countries such as the UAE and Qatar were more stable. The 2022-2023 war between Russia and Ukraine drew energy markets making the oil-based countries unstable. The increase in renewables influenced clean energy stocks since it meant more investment into renewable energy. The market instability in South Africa and in the UAE was slight in 2024 due to the Israel-Hamas war.

Fig. 3 represents Latin American economy and clean energy stocks volatility. The fluctuations were severe in such oil-based countries as Brazil and Mexico which were severely affected by the 2016 oil crisis. The investments in clean energy in 2017 had given some stability but the dependence on oil remained very high in Brazil and Mexico. Brazil and Mexico were hit hard by the market destabilization caused by the COVID-19 pandemic whereas clean energy stocks have been relatively stable. The Russia-Ukraine war that erupted in 2022-2023 led to indirect volatility where the markets in Brazil were sensitive to the changes in energy prices. Peru and Chile were more stable and they had a benefit of copper and lithium exports. The tensions in 2024 between Israel and Hamas led to certain perturbations of the markets especially in Brazil and Mexico.

All the three regions, namely APAC, EMEA, and Americas experienced quite some level of volatility during global events with clean energy stocks proving to be relatively stable during such turbulent times.

3.1.1 Descriptive statistics

The data set shows statistical properties of various indices, such as commodities, such as Clean Energy, Crude Oil, country-specific indices, such as Kuwait and Egypt. The mean of all the indices is 0.000, which means that the average return in the period under observation is neutral or zero. This implies that although individual returns may be different, the performance of these indices has evened out over the time. Nevertheless, the values of standard deviation (SD) indicate high volatility differences. As an example, the standard deviation of Natural Gas and Crude Oil are higher (0.034 and 0.030, respectively), and this means that these indices were more volatile in their returns, whereas Clean Energy has a relatively lower standard deviation of 0.016, which means that it is more stable.

The skew values are mainly negative, indicating the asymmetry of the distributions. Negative skewness implies left-sided bias, where the negative returns are more common than positive returns. As an illustration, the skewness of Clean Energy is -0.240, which implies a minor inclination towards negative returns. Even more extreme examples, like Kuwait (-6.472) exhibit an even more pronounced leftward bias, which means that there are more chances of having more negative returns. South Korea on the other hand will have a positive skewness of 0.078 indicating a slight inclination to positive returns. These findings are consistent with earlier studies, such as (Nepal et al., 2024), who documented heavy tails and skewness in financial return distributions.

On the kurtosis, the values are mostly high with Crude Oil having a very high kurtosis of 68.556, which implies that there is a distribution with heavy tails and large outliers. Egypt has an even higher value of kurtosis of 237.115, which is an indication that the returns of this index had extremely large variations or shocks, and thus there were outliers. Augmented Dickey-Fuller (ADF) statistic has shown that all the indices are stationary, with strongly negative values like -11.966 of Clean Energy, which confirms the notion that their statistical

characteristics do not change over time. This is also confirmed by the ADF p-value of all the indices, which is 0.010, which is much lower than the significance level of 0.05, and therefore these time series are stationary.

All the indices indicate very large values of the Jarque-Bera (JB) statistic, which is used to test normality as 4647.879 in the case of Clean Energy and 2,255,969.671 in the case of Kuwait. These huge JB statistics imply that the distributions of data are not normal with a high probability of extreme price movements or outliers. JB p-value of all indices is 0.000, which once more proves that the data is not normally distributed. Such results imply that the average performance of these indices is neutral, but the volatility, skewness and heavy-tailed distributions imply that the unpredictability and erratic price variations are high. Such significant departures from normality are widely observed in financial time series (Y. Yang et al., 2025).

Table 2: Descriptive Statistics

	Mean	SD	Skewness	Kurtosis	ADF_Stat	ADF_pValue	JB_Stat	JB_pValue
Clean Energy	0.000	0.016	-0.240	9.645	-11.966	0.010	4647.879	0.000
Natural Gas	0.000	0.034	-0.168	5.375	-12.684	0.010	602.341	0.000
Crude Oil	0.000	0.030	-2.749	68.556	-13.744	0.010	453158.455	0.000
Heating Oil	0.000	0.023	-0.731	12.806	-13.501	0.010	10293.025	0.000
Philippines	0.000	0.012	-1.247	17.771	-13.052	0.010	23497.069	0.000
Indonesia	0.000	0.014	-0.229	15.830	-13.883	0.010	17257.498	0.000
Thailand	0.000	0.011	-1.172	20.026	-12.153	0.010	30927.563	0.000
South Korea	0.000	0.012	0.078	10.196	-12.943	0.010	5424.859	0.000
China	0.000	0.013	-0.303	7.064	-13.409	0.010	1768.006	0.000
Malaysia	0.000	0.008	-0.237	11.757	-12.604	0.010	8053.064	0.000
Taiwan	0.000	0.012	-0.594	8.262	-13.567	0.010	3047.263	0.000
India	0.000	0.012	-1.709	23.008	-12.556	0.010	43140.665	0.000
Chile	0.000	0.006	-0.747	15.807	-13.227	0.010	17408.348	0.000
Mexico	0.000	0.009	-0.482	7.706	-13.321	0.010	2415.983	0.000
Peru	0.000	0.017	-0.388	11.220	-12.812	0.010	7137.486	0.000
Brazil	0.000	0.021	-0.917	14.463	-11.902	0.010	14109.877	0.000
Colombia	0	7	-1.337	25.899	-13.488	0.010	55655.812	0.000

Czech Republic	0.000	0.013	-1.157	14.239	-12.725	0.010	13787.679	0.000
Hungary	0.000	0.017	-1.274	17.886	-12.857	0.010	23883.065	0.000
Kuwait	0.000	0.009	-6.472	149.211	-12.443	0.010	2255969.671	0.000
Qatar	0.000	0.010	-1.454	23.215	-14.183	0.010	43675.978	0.000
Saudi Arabia	0.000	0.011	-2.052	33.752	-13.208	0.010	100786.372	0.000
Poland	0.000	0.016	-0.790	14.277	-13.003	0.010	13577.300	0.000
United Arab Emirates	0.000	0.011	-1.932	35.417	-12.661	0.010	111600.652	0.000
Egypt	0.000	0.019	-10.323	237.115	-12.853	0.010	5783704.174	0.000
Greece	0.000	0.018	-1.293	17.927	-12.701	0.010	24032.609	0.000
South Africa	0.000	0.018	-0.441	6.755	-14.042	0.010	1558.246	0.000

3.2 Methodology

3.2.1 Wavelet Coherence

Wavelet Coherence (WTC) does not involve the usual type of econometric equations of linear regression but it is based on localized measures of time-frequency correlation between two time series. But to simplify and make it academically presentable, we may refer to the pairwise relations in the following quasi-econometric form in which wavelet analysis is carried out.

The Continuous Wavelet Transform (CWT) is used to analyze the co-movement between pairs of financial assets and equity indices and then the Wavelet Coherence (WTC) is applied. Wavelet Coherence is a local measure of correlation of two time series in the time-frequency plane.

$$R_{xy}^2(u,s) = \frac{|S(s^{-1}W_{xy(u,s)})|^2}{S(s^{-1}W_{x(u,s)})|^2 . S(s^{-1}W_{Y(u,s)})|^2} \quad (1)$$

Where:

u is the time position,

s is the scale (related inversely to frequency),

$W_{x(u,s)}$ and $W_{y(u,s)}$ are the continuous wavelet transforms of x and y, respectively,

$W_{xy(u,s)} = W_{x(u,s)}$ is the cross-wavelet transform,

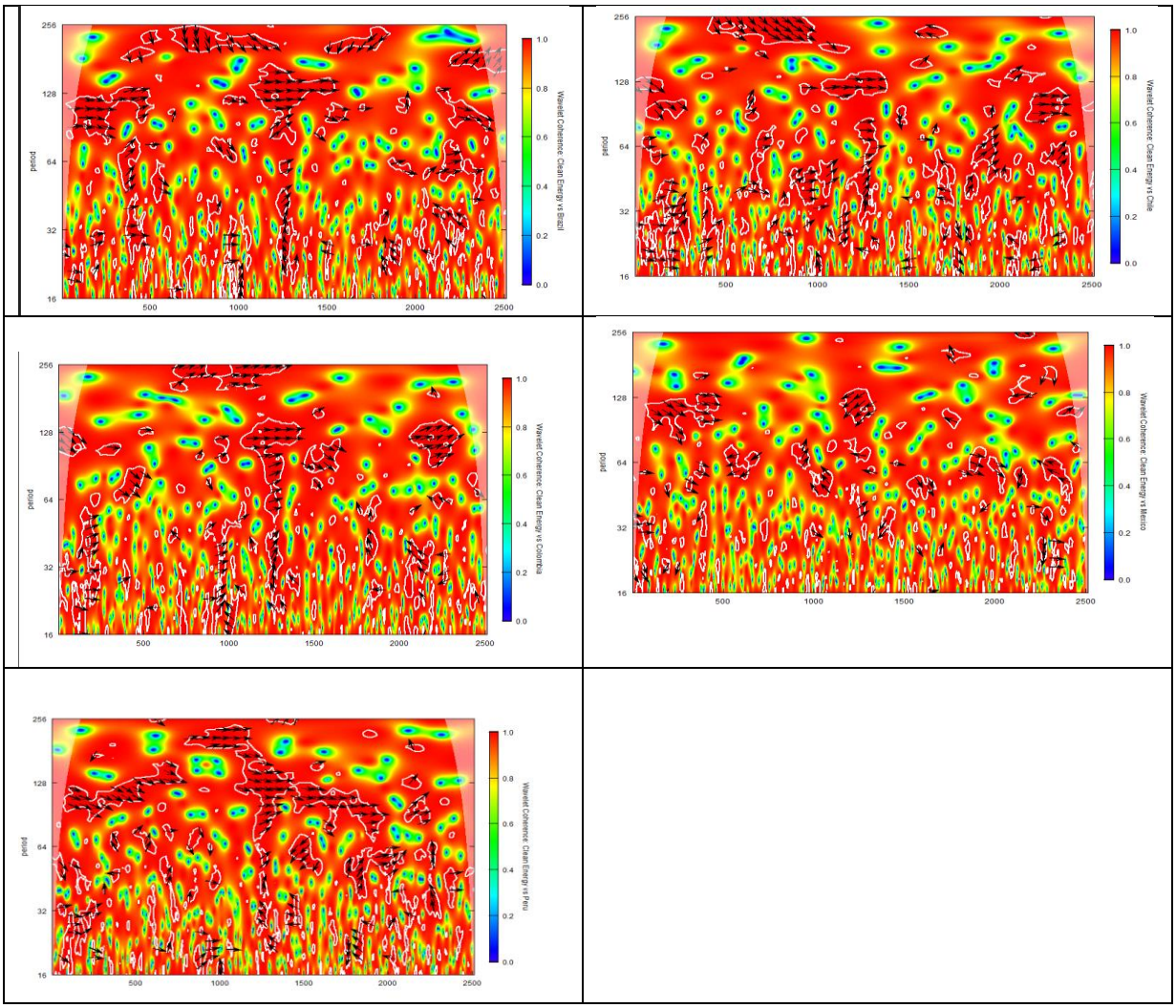
S is a smoothing operator in both time and scale.

This measure takes values in [0,1], where 0 implies no correlation and 1 indicates perfect local correlation at a given time and frequency

4.Data Analysis

4.1 Wavelet Coherence Analysis for Clean Energy and the Americas

Fig.4:Wavelet Coherence for Clean Energy and the Americas



The analysis of the wavelet coherence unveils that Clean Energy has remained a top predictor towards the movements of equity markets in various countries of Latin America in varied crises in the world. This leadership has been witnessed through several time horizons, that is, the short-term, medium, and long-term and the type and cause of crisis determine what leadership will be employed. Clean Energy prices also turned out to be extensively significant predictive signals because unexpected developments in the equity markets of these economies were predated by the corresponding movements in Clean Energy prices given that Clean Energy was a leading variable.

Clean Energy demonstrated leadership in many countries such as Brazil, Mexico, and Chile, especially in the short-term scenario in case of Oil Crisis (1-435). Peru and Colombia showed leadership in the middle term. This trend implies that in the case of the oil price shock, Clean Energy markets probably captured the initial indication of energy transition plans or market responses to increased prices of fossil fuels. To the investor, this highlights the potential of

Clean Energy to act as a harbinger of change in an industry especially where there is increasing demand of alternative sources of energy.

Clean Energy provided a very broad based and persistent kind of regional leadership in the Climate Change period (435-695). Other nations that were examined such as Brazil, Mexico, and Chile were observed to be short-term sensitive to Clean Energy signals though Brazil was found to be short and long-term coherent. Such a powerful impact suggests the growing importance of focusing on sustainability, renewable energy, and ESG-aligned investments, primarily in the nations with decarbonization policy on the agenda. To investors, monitoring Clean Energy would have provided them with useful insights of the economic and market changes brought about by legislation on the issue of climate and sustainability efforts by the people.

Clean Energy leadership has persisted within the group of countries, especially in the short-term, during the COVID-19 pandemic (1213-1731). The countries that demonstrated leadership were Brazil, Mexico as well as Chile, and medium-term coherence was observed in Peru and Colombia. This was probably the time of green recovery demand, and Clean Energy was used globally as the ingredient of recovery plans and sustainability stories of governments and investors. The availability of Clean Energy leadership, especially on the medium-term basis, implies that the industry dealing with the renewable energy was viewed as the structural growth story during the global crisis, which sent potential messages to investors so that they could reconfigure their portfolios.

During the period of the Russia-Ukraine War (1753-2032), the presence of Clean Energy as a strategic value gained new requirements. Brazil, Mexico and Chile performed leadership especially in the short term. It is important to note that Chile and Brazil were coherent both in the medium and long term. This can be interpreted to mean that the geopolitical insecurity due to the war might have enhanced the significance of Clean Energy as energy diversification and market resilience tool. To investors in the Americas Clean Energy markets were some of the first to give signals of the direction of energy transition and the necessity of the countries to decrease their reliance on the import of unreliable fuel sources.

And finally, the Clean Energy leadership proved to be of great importance to long term horizons in terms of the Iran-Israel War (2252-onwards). Short-and-medium-term coherence was exhibited by countries such as Chile, Peru and Mexico whereas long term coherence was exhibited by Brazil and Colombia. It means that the herculean attention to the energy security and alternative sources of energy within the global arena was even more evident where the Clean Energy markets have played a very important part in deciding the long run investment planning. To investors, this indicates that Clean Energy trends may give a good sense on geopolitical risks and what this means to the energy sector.

Finally, another conclusion is that Clean Energy has been developed as a strong and multi-crisis leading indicator of the Americas equity markets. Its leaders are present throughout time horizons and geographies, especially with its strongest presence in times of climate-related upheavals and geopolitical energy disruptions. To investors, the New Energy is an area that should not only be followed using sectoral ETFs, green utilities, and innovation indexes, but also as an overall portfolio positioning. The actionability of the sector in command of the equity marketplace strengthens its strategic position as a theme investment and a progressive surrogate of economic transition in the Americas.

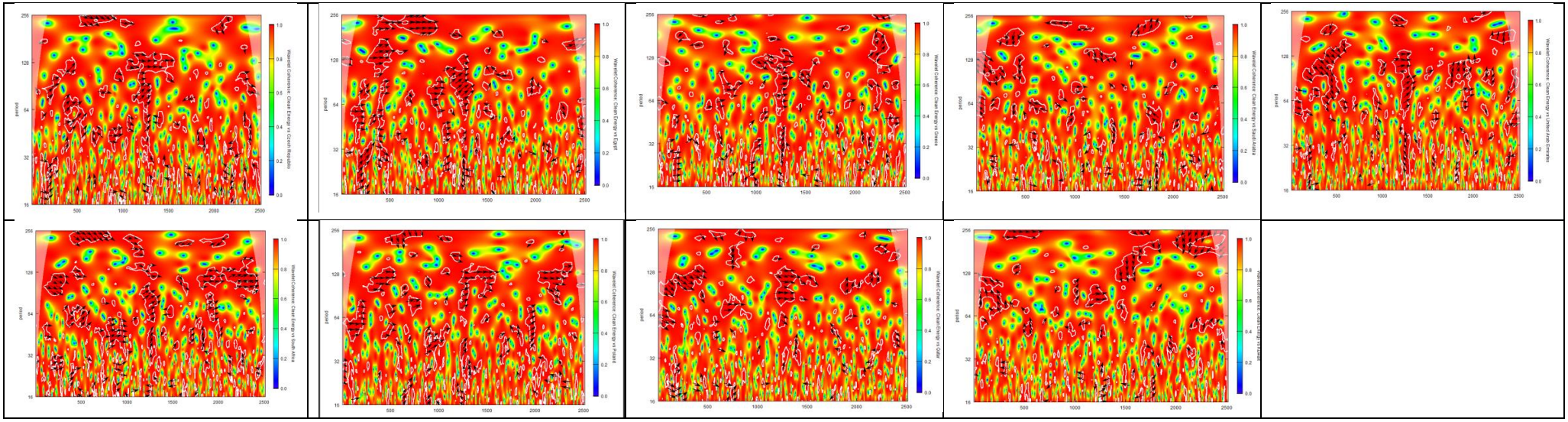


Fig 5: Wavelet Coherence Clean energy to EMEA

Wavelet Coherence Analysis for Clean Energy and EMEA

The analysis of the wavelet coherence (Table 1 attached) shows that Clean Energy is a lead indicator of equity markets in different EMEA (Europe, Middle East, and Africa) countries in multiple crises in the world. It is a leadership that has been seen in various time horizons that include short-term, medium-term, and long-term depending on the crisis being dealt with at any given time. The existence of Clean Energy as a leading variable eludes to the fact that movements of Clean Energy markets most of the time preceded the movements in equity markets and thus served investors well as predictive variables.

At the time of the Oil Crisis (1-435), Clean Energy provided leadership in such countries as Egypt, Saudi Arabia, and Poland in which short-term coherence was the most important characteristic. Egypt and Saudi Arabia were exceptional as they demonstrated the leadership, about how Clean Energy reacted on the initial jolt in the global oil prices. This means that investors might have picked clean energy as a precursor of the changes in energy markets, particularly in economies that rely on oil. The trends of clean energy provided valuable insight into the possible energy policy or the transition to the alternative sources of energy, therefore, providing valuable investment indicators during the upheavals of oil.

During the Climate Change period (436-695), the leadership of Clean Energy was widespread and rather stable, with such countries as Greece, Egypt, and Poland showing strong short-term and medium-term coherence. Egypt and Poland, to be more specific, demonstrated leadership both in the short-term and medium-term perspectives. This shows the increasing significance of clean energy as nations in the EMEA region became more interested in decarbonizing and renewable energy networks. By focusing closely on Clean Energy movements, investors of such areas could have gained insight into the various expected changes in climate policies, green investments, and the overall transition towards the sustainable economy.

In the short term, during the Covid-19 pandemic (1213-1731), Clean Energy remained a leader in such markets as Egypt, Saudi Arabia, and Poland. Such countries as Egypt demonstrated both short and medium-term alignment with Clean Energy, implying that Clean Energy assets were seen as both safe-haven assets and a component of a post-pandemic sustained growth narrative during the pandemic. The structural growth theme of Clean Energy was observed in Saudi Arabia with its long-term consistency, where the activities were to restore with the theme of sustainability and green economic stimulus. To the investors, the period displayed the ability of Clean Energy to surpass the temporary turbulence and conform to the long-term realities of energy transition.

The period of war between Russia and Ukraine (1753-2032) became a time when the strategic importance of Clean Energy rose. Saudi Arabia, Egypt and Poland were well coherent in the short term, and Poland in the short and medium term. The geopolitical tensions in the energy sector drove the importance of Clean Energy as countries were in quest to diversify their energy sources. To investors, Clean Energy market was an early indicator of the changing parameters of energy security, and geopolitical crisis-induced rebalancing in the market.

At the long horizon, it is particularly evident that the Clean Energy leadership in countries such as Saudi Arabia and Egypt was in the Iran-Israel conflict (2252-onwards). These regions have shown that Clean Energy trends were already part of the long term economic plans, and we could see how the wider stories of national growth and risk were shaping. Shareholders are advised to pay attention to the increasing role of Clean Energy in the emerging markets, which is gaining deeper integration throughout the international financial framework, facilitated by the international climate funds, infrastructure development, and green finance projects.

This has been conclusively shown when it is evident that Clean Energy has been a powerful and a robust leading indicator in the equity market in the EMEA region. Its leadership is visible in numerous crises and time horizons, where especially strong indications offer climate-related disturbances and geopolitical shocks in energy. To investors, this means that the Clean Energy has to be tracked not only as a sustainability targeted investment venture but also as an anticipatory challenge of market directions and economic changes in the future. Second, Clean Energy restructuring maintains the thematic investment orientation of the business, as well as serves as a leading indicator of economic transition in EMEA economies.

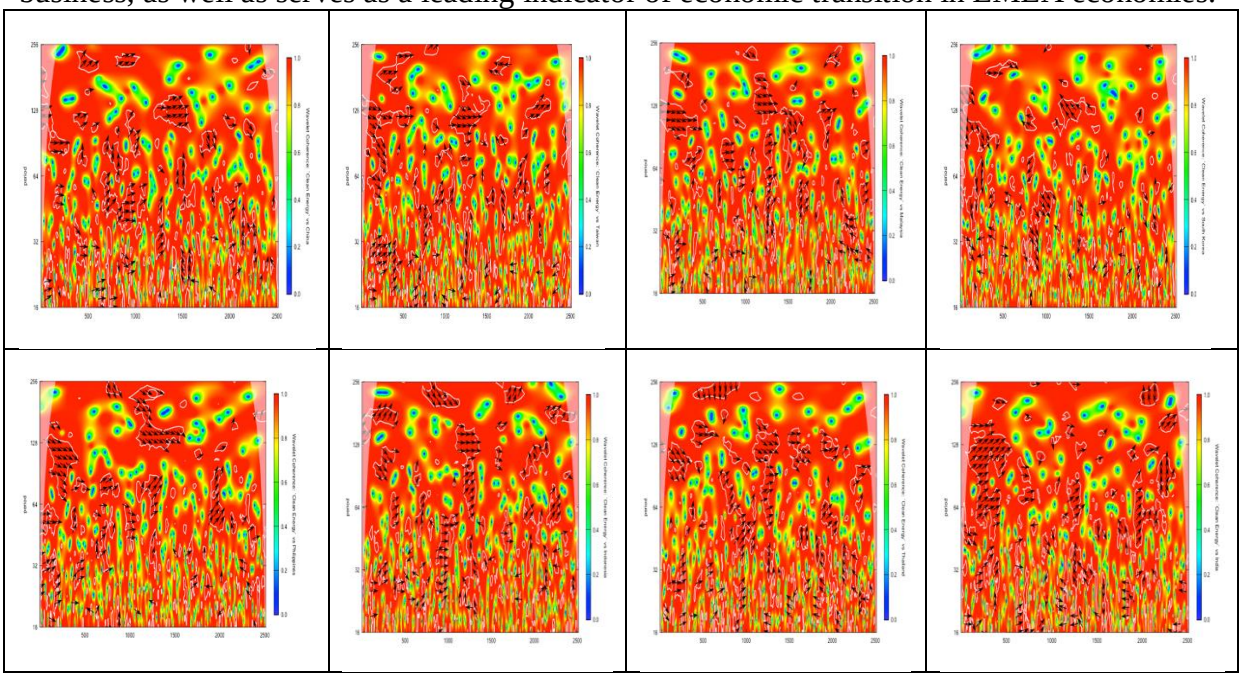


Fig 6: Wavelet Coherence Clean Energy vs APAC

Wavelet Coherence Analysis for Clean Energy and APAC

The wavelet coherence analysis shows that Clean Energy has always been able to inform equity markets of various APEC countries in various world crises. This leadership can be seen to exist throughout several time circles in short, medium and long term and, accordingly, can be different regarding nature and origin of the crisis. The prominence of Clean Energy as a prime variable suggests that the fluctuations in prices of Clean Energy occurred before the alteration in the equity markets of these nations thus providing significant lead indicators to investors.

The short terms leadership demonstrated by clean energy during the Oil Crisis (1-435) was mainly witnessed in various economies where clean energy led during the Oil Crisis, i.e., the Philippines, Indonesia, Thailand, China, Malaysia, Taiwan and India. India portrayed both medium and short-terminal leaderships. The pattern suggests that the initial indicators of clean energy markets could be related to interests in alternatives, which was observed in fossil fuel shocks and went ahead of moves into equity markets in energy-migrating or energy-importing economies. Clean energy is one of the factors reflecting an expected policy change or technological replacement by the investors that the investors will have an indication of future needs even in oil-driven crisis.

During Climate Crisis period (436695), there was an overall and a consistent leadership on the issue of clean energy. Other countries such as Phillippines, Indonesia, Thailand, China, Malaysia and Taiwan were either time-bound (responsive to clean energy signals) and or short-to-long term coherent as with Indonesia. This powerful force highlights the greater

emphasis on decarbonization, renewable infrastructure and environmentally sustainable governance (ESG) investment when faced with climate-induced shifts. Theoretically, an investor in such economies would have been well served monitoring clean energy trends so they could have predicted the impact of climate legislation or the general conversation on sustainability on equity values, especially in the energy, industrials and transport sectors.

The COVID-19 pandemic of (12131731), remained market selective and as the market leader in clean energy, market leader performance occurred across markets such as Indonesia, Thailand, China, Malaysia, Taiwan and India in the short-term primarily, with Philippines, Indonesia, Malaysia and India also demonstrating both short and medium-term coherence. The South Korea that has Long-term coherence. Clean energy equities could have been safe-haven and recovery-focused investments, since they were boosted by green stimulus packages around the world, and green stories beyond the COVID crisis. Having seen the medium-term leadership in the pandemic indicates that the clean energy sectors were seen as a structural growth story, even in the short-term economic disruption. This signal would have enabled investors to turn over capital to sectors that could benefit long-term decarbonization and energy transformation.

This is the strategic value of clean energy that was amplified during the period of the Russia Ukraine War (1753-2032). The countries that led in Short-term singles of coherence were Philippines, Thailand and India since they showed short and Medium-term. It is worth noting that Indonesia and Taiwan are those countries that demonstrate both short-term and long-term dependency on clean energy, which could be seen as the indicator of the enhanced role of clean energy within geopolitical energy-market shocks. The dynamism of clean energy markets also offered valuable precursors of shifting sectors and investment rebalancing to investors in such locations when it came to energy diversification and resilience.

Finally, there was the Iron-Israel War (2252-onwards). This is because clean energy leadership exist in the developing economies such as India and Indonesia especially at the long horizon and that Indonesia Thailand, Malaysia and India are coherent in the short horizon and that Thailand is coherent in short and Medium-term. It is a clue to globalization of finance clean energy and the increasing integration into national growth and risk narratives. This means to investors, that clean energy may have a broader applicability as a predictive engine, both in well-established ESG markets, and future markets in emerging economies, where green financing is attracting attention, as are infrastructure development and internationally supported climate funds, and which have a growing role in informing equity expectations.

Our results align with several recent empirical investigations that highlight dynamic interlinkages between energy markets, green assets, and financial markets during periods of uncertainty and geopolitical stress. For instance, Basdekis et al. (2022) demonstrated significant time–frequency interdependencies between crude oil, stock indices, and exchange rates during the Russia–Ukraine war using wavelet coherence, emphasizing how crises amplify market interconnectedness. Similarly, the study by Haq et al. (2023) identified strong short- and long-term co-movements between green bonds, sustainable cryptocurrencies, and sustainability indices, supporting our evidence of differentiated behavior across frequencies and investment horizons. This is further reinforced by Karkowska and Urjasz (2023), who found that extreme events like the COVID-19 pandemic and the Ukraine war increased volatility spillovers and co-movement between clean and traditional energy markets, indicating structural shifts in asset dynamics. Additionally, Deng et al. (2023) used wavelet coherence to show the heterogeneous and time-varying nature of risk contagion between clean energy stocks and metal markets during crises, consistent with our findings of frequency-dependent relationships and shifting lead–lag structures. Together, these studies

support the robustness of our results and affirm the importance of using advanced time–frequency tools like wavelet analysis to capture nonlinear, dynamic dependencies in times of global disruptions.

To sum up, the green energy has become a relative dynamic and multi-crisis indicator of equity market in APEC economies. Its leadership can be observed over a wide geographic area and spanning different-time periods, but especially evident in climate related disruptive events and geopolitical energy shocks. To the investors, this poses an intention to study in detail the clean energy patterns of sector-specific ETFs, green utilities and innovation indexes on not just the sustainability exposure but more specifically the overall portfolio exposure. The fact that the industry dominates equity markets reiterates the strategic role of the industry as a thematic investment and a growth-oriented indicator of economic change in the APAC Economies.

5.Conclusion

This study presents robust evidence on the evolving role of clean energy stocks in shaping the volatility and interdependence structure of equity markets across APAC, EMEA, and the Americas during systemic global events between 2015 and 2024. Descriptive statistics show high standard deviations, significant skewness, and non-normal distribution patterns signal deep volatility and structural asymmetries — justifying the use of non-linear analytical frameworks.Through wavelet coherence analysis, we find that clean energy exhibits dynamic linkages with regional equity indices — varying across time and frequency domains depending on the nature and intensity of the crisis.

In APAC, markets like India, Taiwan, and Indonesia reveal strong medium- to long-run coherence with clean energy, especially during the COVID-19 pandemic and the Russia–Ukraine conflict. Clean energy often acted as a leading indicator, offering early market signals. In EMEA, while oil-based economies such as Saudi Arabia and Kuwait remain volatile during energy shocks, European countries like Poland and Greece show reduced coherence due to diversification and clean energy investment — underscoring clean energy's stabilizing influence.In the Americas, Brazil and Mexico experienced persistent volatility, but countries like Peru and Chile, buoyed by critical mineral exports (copper, lithium), demonstrated more stable co-movements, highlighting regional resource-based differentiation. The results strongly suggest that clean energy is not only resilient during crises but increasingly shapes investor behaviour and regional market sentiment.Implications of this study are both academic and practical. For policymakers, it underscores the importance of integrating clean energy policies not just for environmental goals but also for financial stability and resilience. For investors, clean energy offers both diversification benefits and a forward-looking signal of regional equity performance, especially under systemic stress.

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