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Time-varying Relationship between Fossil Fuel-Free Energy Indices and Economic Uncertainty: Global Evidence from Wavelet Coherence Approach

Farah Durani*

University of Business and Technology, Jeddah, Saudi Arabia. *Email: farahdurani@gmail.com

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ABSTRACT

Considering the abysmal environmental impacts of anthropogenic activities, the entire world has been striving to shift toward a green economy. Also, the transition to a greener economy entails green financing, which escalates the pace and performance of environment-friendly economic activities. However, uncertain economic conditions might be a hindrance to green financing. Based on this, I investigate the co-movement of fossil-fuel-free energy equity indices returns and Twitter-based economic uncertainty using a wavelet coherence approach. The findings document that global, the US, and Japanese fossil-fuel-free indices show strong and positive co-movement with Twitter economic uncertainty for short- and medium-term investment horizons. However, a weak positive co-movement is observed during the Russia-Ukraine war. Based on these interesting findings, I suggest many policy implications.

Keywords: Renewable Energy Investment, Energy Markets, Twitter-based Economic Uncertainty, Fossil Fuel-free Energy Equity, Russia-Ukraine War, COVID-19

JEL Classifications: D53, F37, G11, G15

1. INTRODUCTION

Environmental degradation has witnessed a rising trend since the commencement of the industrial revolution. It is worth reporting that environmental degradation exerts detrimental impacts on human life and the ecosystem. Not only this, but environmental issues such as floods and droughts exert an impact on agricultural and industrial output. Given the economic effects of environmental degradation, the world is striving to control this aforementioned issue to save the current and future generations (Apergis et al., 2023a, b; Payne and Apergis, 2021). It has been noticed that environmental degradation depends on Greenhouse gases, which are being emitted in the air mainly due to anthropogenic activities. Hence, economic activities are the culprit for these gases. Further, energy consumption is a significant contributor to greenhouse gases. Figure 1 explains the world's man-made greenhouse gas emissions by sector. As can be observed from Figure 1, around 73% of gases have been emitted by the energy sector.

It is worth highlighting that the share of fossil-fuel-based energy is significantly high compared to renewable energy. This scenario is depicted in Figure 2, reporting that renewable energy has a minor share in the global energy mix. Therefore, curbing environmental degradation needs renewable energy utilization. The upsurge in renewable energy share requires extensive investment in infrastructure and renewable energy technologies. For instance, wind farms, energy storage facilities, and solar panel development are highly dependent on investment. Similarly, replacing fossil fuel-based power-generating systems with renewable energy systems is also calling for investment. This point has also been discussed in the recent World Energy Investment Outlook that investment in renewable energy is still below its desired level.

Figure 1: Global greenhouse gases emissions by sector[1]

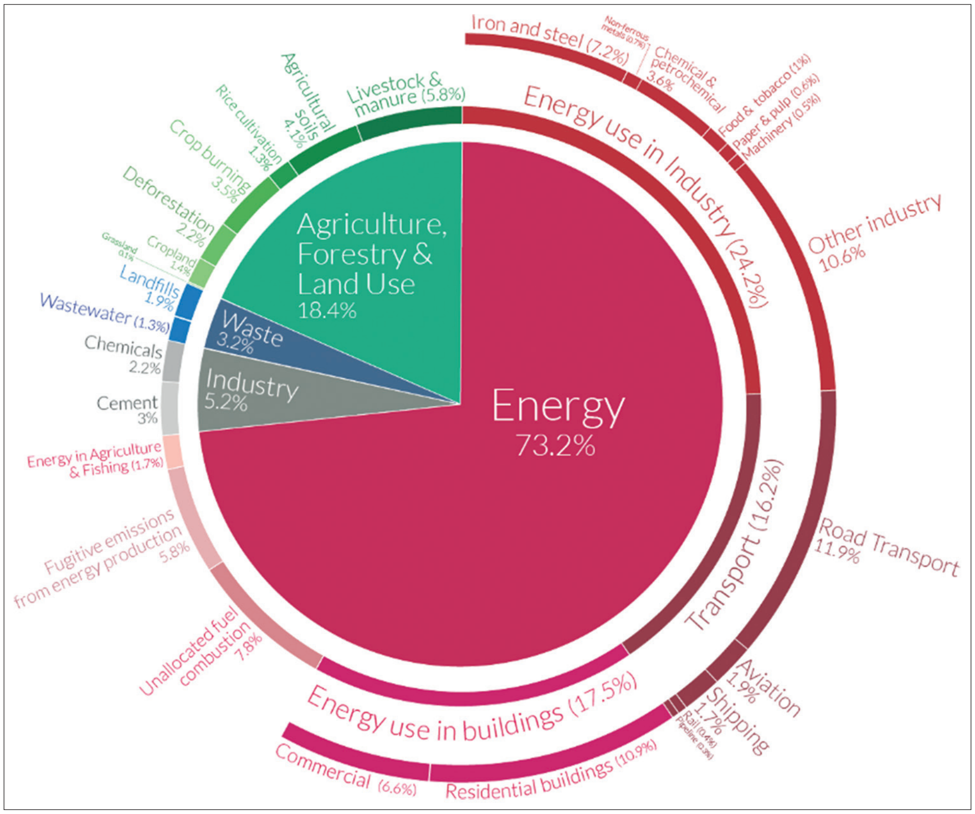
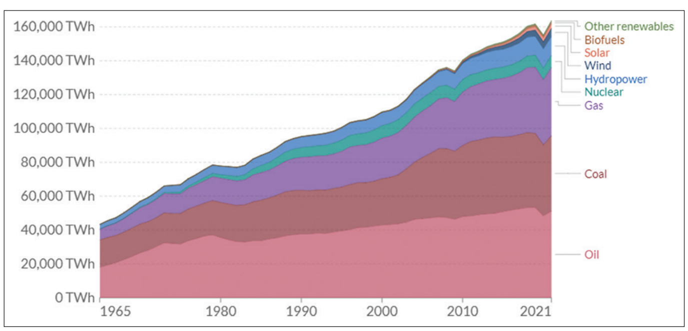


Figure 2: Global energy mix[2]



Moreover, the report also highlights some key challenges that are hindrances to renewable energy transition.[3] The report on World Energy Investment highlights economic uncertainty, outbreaks, and geopolitical conditions as the factors affecting renewable energy investment. It is argued that economic uncertainty propels investors to delay their investment plans, which in turn plunges investment (Anser et al., 2021). Similarly, uncertainty also affects returns on energy investment and hence impacts energy markets (Lin and Li, 2022; Syed et al., 2023). Hence, it could be concluded that economic uncertainty affects energy investment. The prior literature also confirms the negative relationship between economic uncertainty and energy investment. For instance, Zhao (2022) concludes that uncertainty plunges clean energy investment. Similar results are also reported by Wang et al. (2022). Bouri et al. (2022) argue that uncertainty impacts both clean and fossil fuel energy stocks. It is worth noting that there exist contrasting conclusions about the exact impact of economic uncertainty on renewable energy investment in the prior literature, therefore, it is essential to reinvestigate this issue.

On top of this, there is sparse empirical evidence on the economic uncertainty-renewable energy investment nexus amidst the COVID-19 and the Russia-Ukrainne war periods. The recent COVID-19 pandemic affected most economies, which calls for interventions by governments and policymakers. During the first wave of COVID-19 most governments-imposed lockdowns, social distancing, mass quarantines, and border closures. These mobility restriction measures severely reduced the oil demand by over 20% at the start of the COVID-19 pandemic which results in the reduction of oil prices and investments in energy sectors declined by 400 billion US dollars as compared to the pre-pandemic level of 2019 (IEA, 2020). Investors look for safe havens against the volatility of fossil-fuels[4] which transmit volatility shocks to other sectors and investors consider investing in clean energy, gold, and Bitcoin to diversify their investments (Song et al., 2021; Wang et al., 2022; Yousaf et al., 2022).

The energy shocks during COVID-19 accelerated the global transition from fossil fuels to clean energy. The COVID-19 pandemic disrupted the fossil-fuel markets and highlighted the need to move towards climate-friendly financial assets (Hosseini,

1 https://ourworldindata.org/emissions-by-sector
2 https://ourworldindata.org/energy-mix#:~:text=Globally%20I%20get%20the%20largest,than%2080%25%20of%20energy%20consumption.
3 https://iea.blob.core.windows.net/assets/760a2737-dc8e-4365-ab0a-70aee72978a5/WorldEnergyInvestment2023.pdf

4 Fossil fuel reserves are technically and economically recoverable sources of natural gas, thermal coal and crude oil.

2020; Jiang et al., 2021; Steffen et al., 2020). The European government constructed the €225 billion recovery fund for energy transition, and the US government also aims to halve greenhouse gas emissions by 2030 and reach a net-zero emissions[5] target by 2050[6]. China also intends to become carbon-neutral by 2060[7]. The global corporate sector also set targets to achieve net-zero emissions by 2050 (Bolton et al., 2022; Srinivasan et al., 2022).

The above ambitious net-zero emission targets by governments and the corporate sector attracted academics' and investors' attention in financial markets. The COVID-19 pandemic increases investor preferences towards sustainable stocks by considering the society, environment, economic and regulatory issues. The COVID-19 pandemic also highlighted the potential risks of investing in energy markets. Therefore, investors shift their investments toward sustainable stocks during COVID-19 as they expect these assets' long-term growth (Singh et al., 2022).

These sustainable financial assets also outperform the traditional assets during the COVID-19 pandemic, for instance, ESG stocks (Broadstock et al., 2021; Eisenkopf et al., 2022; Rubbaniy et al., 2022; Singh et al., 2022), rare earth metals (Hanif et al., 2023; Zheng et al., 2022), green financial assets (Huang et al., 2023; Kamal and Hassan, 2022; Ren and Lucey, 2022).

These studies highlighted those green financial assets performed Ill during the COVID-19 pandemic as compared to traditional assets this can be related to investors' demand for sustainable assets. The fossil fuel-free indices are also an attractive option for investing in equity markets as they exclude firms having significant fossil fuel reserves and being involved in producing fossil fuels. These indices include the firms engaged in sustainable activities. These fossil-fuel-free indices may minimize the risks associated with energy sector investments and support the transition to a low-carbon economy.

The existing studies (Ritchie and Dowlatabadi, 2015) discussed the fossil-fuel divestment literature by considering its portfolio performance and diversification potential. However, Markowitz (1952) modern portfolio theory suggests that investors can construct portfolios to maximize or optimize the expected returns on a given level of market risks. Though, selecting constrained investment opportunities may limit the portfolio returns compared to an unbound portfolio at a given risk level (Bakar and Rosbi, 2018; Dai et al., 2022). However, the objective of investors is to construct a portfolio that provides higher returns at a given level of risk (Bakar and Rosbi, 2018).

The existing fossil-fuel divestment literature finds contrasting evidence as its investment portfolios are influenced by macroeconomic factors, financial crises, or health-based crises. Some authors suggest that fossil-fuel divestment increases the costs of investing and reduces portfolio diversification due to stranded assets (Cornell, 2015; Fischel and Lexecon, 2015; Green and Newman, 2017; Trinks et al., 2018). Ethical investors rebalance their portfolios to reduce their carbon footprint (Frankel et al., 2015; Scipioni et al., 2012). Conversely, (Ayoubi and Enjolras, 2022; Heaps et al., 2016; Henriques and Sadorsky, 2018; Hunt and Iber, 2019; Yook and Hooke, 2020) suggests that investments in fossil-fuel indices do not harm and fossil-fuel-free assets outperform the traditional indices as Ill as cut the carbon footprint of portfolios. This scarce literature on fossil-fuel divestment ignored the economic conditions and financial turmoil impact of the performance of the fossil-fuel-free indices. The existing studies also used various methods and different samples and time-span, giving them contrasting results.

The primary motivation of this study is to fill the gap in the existing literature on fossil-fuel-free indices and economic uncertainty. I contribute to the existing literature in many dimensions. First, this is the earliest attempt to probe whether economic uncertainty affects fossil-fuel-free energy stocks. Secondly, this study analyses how COVID-19 impacts the uncertainty-fossil fuel free stocks nexus. Third, I gather data on fossil fuel-free stocks from several regions and hence conduct a global analysis that is disregarded in the prior literature. Fourth, I employ the wavelet coherence approach, presenting the time-frequency comovement. Unlike other methods (e.g., OLS-based regression), this approach probes the relationship between two variables in the long, medium, and short-run at each point of the selected period. Finally, I perform a sensitivity analysis to provide robust findings.

2. DATA

Considering the objective of this study, I utilize the daily time series data covering the span from 7th January 2013 to 17th June 2022. The period of the study covers both the COVID-19 pandemic and the Russia-Ukraine war crisis span. Hence, this study could analyze the relationship between uncertainty and fossil fuel-free indices during these two events.

Next, the dependent variables include the S&P 500 Fossil Fuel Free Index, S&P Global 1200 Fossil Fuel Free Index, S&P Asia 50 Fossil Fuel Free Index, S&P/ASX All Australian 50 Fossil Fuel Free Index, S&P Europe 350 Fossil Fuel Free Index, S&P Latin America 40 Fossil Fuel Free Index and S&P/TOPIX 150 Fossil Fuel Free Index. These indices cover the performance of companies across the world since the indices from different regions of the world are gathered. These aforementioned indices elucidate an investment approach or portfolio that excludes companies involved in the extraction, production, or use of fossil fuels. It is a strategy that aims to divest from fossil fuel-related industries and instead invest in companies that are considered environmentally friendly or sustainable. Further, the data on these aforementioned indices are gathered from the Datastream database. Next, I calculate daily log returns from the aforementioned index prices as equity market investors are more interested in returns during financial turmoil.

5 Net zero emissions is a situation when an entity's greenhouse gas (GHG) emissions are adjusted by GHG removal measures, having no net impact on environment.

6 https://www.mckinsey.com/capabilities/sustainability/our-insights/navigating-americas-net-zero-frontier-a-guide-for-business-leaders#/

7 https://www.economist.com/china/2020/09/24/china-aims-to-cut-its-net-carbon-dioxide-emissions-to-zero-by-2060

Further, the independent variables include the Twitter-based economic uncertainty (TEU_ENG)[8] proposed by Baker et al. (2021) and the US newspaper-based economic policy uncertainty by Baker et al. (2016). I download these two datasets from *http://www.policyuncertainty.com/index.html*. It is worth noting that Baker et al. (2021) use the text mining approach on daily tweets related to economic uncertainty for developing the index.[9] On the contrary, Baker et al. (2016) utilize data from daily newspaper articles to construct an index for economic policy uncertainty.[10] Twitter-based economic uncertainty is used to test the time-varying performance of fossil-fuel-free indices across time and frequency domains.

The snapshot of the data given in Table 1 presents descriptive statistics of the considered variables. The average returns of fossil-fuel-free indices (except S&P LAT40) are positive with a low standard deviation, indicating low variations in returns of these indices during the sample period. The kurtosis values are <24, which suggests the non-normality of returns that is frequently observed while handling the financial dataset (Blau, 2017; Karoglou, 2010). The stock returns distribution is non-normal, showing its higher variation across time as returns depend on different macroeconomic factors and vary with changes in uncertainty levels in financial markets (Blau, 2017; Choi and Nam, 2008). The averages of Twitter economic uncertainty and US economic uncertainty are 107% and 114%, respectively.

3. METHODOLOGY

The wavelet coherence approach is used in this study to investigate the co-movement of fossil-fuel-free indices and economic uncertainty at the time and frequency domains. The traditional time-series models only consider time dimension; However, the wavelet coherence approach proposed by Torrence and Compo (1998) analyzes the co-movement of nonlinear and asymmetric time-series in the short-, medium-, and long-run frequencies (investment horizons) from a lead-lag relationship perspective. The wavelet coherence approach is also useful for different types of investors as short-term investors focus on short-term variations over a period of days and long-term investors analyze the trend of financial time series over years. Consequently, the wavelet coherence approach can help investors to identify investment opportunities during periods of higher uncertainty and improve portfolio performance by considering different investment horizons.

Further, the stationarity assumption is also not required in the wavelet coherence approach which is a common characteristic of financial time-series data (Aguiar-Conraria and Soares, 2011; Jiang and Yoon, 2020; Rubbaniy et al., 2022). The wavelet coherence approach is a time-varying method and its results are not affected by changes in the sample, unlike traditional regression-based estimations which are based on average(mean) effects (Aloui and Hkiri, 2014; Dimitriou et al., 2020; Fareed et al., 2020; Kang et al., 2019).

The existing studies (Henriques and Sadorsky, 2018; Hunt and Iber, 2019; Trinks et al., 2018; Yook and Hooke, 2020) investigate the performance of fossil-fuel-free indices by using time-series models i.e., time-series OLS regression with portfolio implications (Hunt and Iber, 2019; Plantinga and Scholtens, 2021; Trinks et al., 2018), GARCH and GO-GARCH models (Henriques and Sadorsky, 2018), logistic regression (Egli et al., 2022), Fama-French factor models (Al Ayoubi and Enjolras, 2022; Reboredo et al., 2019). However, these approaches fail to consider the time-varying co-movements of fossil-fuel-free indices; specifically, the performance of these equity indices with economic uncertainty is not discussed in existing studies. Hence, the advantage of the wavelet coherence approach is that it reports the time-varying impact of economic uncertainty on fossil fuel-free indices.

The wavelet coherence approach by Torrence and Compo (1998) is applied to analyze co-movement between 2 time series across time and frequency dimensions. The wavelet transform is explained by $W_x(u,s)$ and $W_y(u,s)$ in the following Equation (1):

$$W_{xy}(u,s) = W_x(u,s)W_y^*(u,s) \tag{1}$$

In Equation 1, the u is the position index, s is frequency, and * shows the complex conjugate.

8 Twitter Economic uncertainty analyze tIets containing different English keywords "'uncertain', 'uncertainly', 'uncertainties', 'uncertainty'. Keywords related to the economy are the following: 'economic', 'economical', 'economically', 'economics', 'economies', 'economist', 'economists', 'economy'" regarding uncertainty and warning signals about economic and financial shocks in financial markets.

9 Refer to Baker et al. (2021) for a detailed discussion on the methodology.

10 Refer to Baker et al. (2016) further details on the methodolo

Table 1: Descriptive statistics

Variables	Obs.	Mean	Median	Std.Dev.	Skewness	Kurtosis
S&P 500 Fossil Fuel-Free Index	2168	0.001	0.001	0.011	−0.992	22.656
S&P 1200 Global Fossil Fuel-Free Index	2168	0.000	0.001	0.009	−1.313	23.731
S&P Asia 50 Fossil Fuel-Free Index	2168	0.000	0.001	0.011	−0.171	6.155
S&P ASX 50 Fossil Fuel-Free Index	2168	0.000	0.001	0.010	−0.937	16.954
S&P EU 350 Fossil Fuel-Free Index	2168	0.000	0.001	0.010	−1.056	15.666
S&P LAT40 Fossil Fuel-Free Index	2168	−0.000	0.000	0.016	−0.875	11.634
S&P TOPIX160 Fossil Fuel-Free Index	2168	0.000	0.000	0.012	−0.261	6.776
Twitter Economic Uncertainty	2168	106.408	79.775	93.163	3.303	29.077
US Economic Policy Uncertainty	2168	113.343	87.535	88.691	2.598	11.877

Reports Twitter-based economic uncertainty, and US newspaper-based economic policy uncertainty as measures of volatility. Further, Table 1 shows the selected descriptive statistics (mean, median, standard deviation, skewness, kurtosis) of S&P 500 Fossil Fuel Free Index, S&P 1200 Global Fossil Fuel Free Index , S&P Asia 50 Fossil Fuel Free Index, S&P ASX 50 Fossil Fuel Free Index, S&P EU 350 Fossil Fuel Free Index, S&P LAT40 Fossil Fuel Free Index and S&P TOPIX160 Fossil Fuel Free Index daily log returns. Source: Datastream database

The wavelet coherence is the squared absolute value of smoothed cross-wavelet spectra normalized by the product of smoothed discrete wavelet poIr spectra of each time series is explained in the following Equation (2).

$$R^2(u,s) = \frac{\left| S\left(s^{-1}W_{xy}(u,s)\right)\right|^2}{S\left(s^{-1}\left|W_x(u,s)\right|^2\right) S\left(s^{-1}\left|W_y(u,s)\right|^2\right)} \quad (2)$$

In Equation 2, the S is the smoothing operator, squared wavelet coherence coefficient value is within the range of 0 and 1[$0 \leq R^2 (u,s) \leq 1$], bounded by a black line. In the wavelet coherence plot, I define the intensity of coherency between 2 time series using a color heat map which is within ranges from blue (close to zero) to red to high (close to one) coherency or co-movement.

Though, R^2 (u,s) fail to distinguish positive and negative co-movement further Torrence and Compo (1998) calculate the phase differences using deferral signs in uncertain 2-time series. Additionally, I explain the wavelet coherence approach with phase difference in the following Equation 3;

$$\phi_n(s) = \tan^{-1} \frac{imaginary\left[S\left(s^{-1}W_n^{xy}(s)\right)\right]}{real\left[S\left(s^{-1}W_n^{xy}(s)\right)\right]} \quad (3)$$

The direction of co-movement between 2 time series x and y in the wavelet coherence plot is explained with arrows. Where, rightward-directed arrows →:x" and "y" show in-phase (Positive co-movement), leftward-directed arrows ←:x" and "y" indicate an anti-phase relationship (Negative co-movement)." While downward arrows indicate ↓: x" leading "y" by "90° (First Series is Leading) and ↑: y" leading "x" by "90° (Second Series is Leading).

4. EMPIRICAL RESULTS

It is evident that the uncertainties about the outlook of global economies can affect the demand and supply of (non) renewable energy sources. As a result, investors' preferences regarding energy-related financial assets are expected to change. Moreover, the recent COVID-19 pandemic and the Russia-Ukraine war also affect the fossil-fuel market due to demand and supply shocks. As a result, investors look to invest in renewable energy assets to diversify their investments and reduce reliance on fossil fuels. Therefore, this study applies the wavelet coherence approach to test the performance of fossil-fuel-free equity indices with Twitter-based economic uncertainty index at time and frequency domains in Figure 3. With the wavelet-coherence approach, we can detect co-movement at different frequencies with the identification of a lead-lag relationship. This approach is superior to other regression-based approaches used in existing studies conducted on fossil-fuel-free indices for testing time-varying performance at the time and frequency domains.

Figure 3 (1a-g) presents the findings of co-movement between fossil-fuel-free equity indices returns and Twitter economic uncertainty by using the wavelet coherence approach. On the x-axis, time is represented (i.e., the number of days), whereas the y-axis reports the frequency (i.e., the short-, medium-, and long-run). The downward arrows in (□) Figure 1a indicate strong and positive co-movement between S&P 500 fossil-fuel free index returns and Twitter economic uncertainty during the COVID-19 pandemic in 16-256 and 400 days frequency bands (medium and long-term) with the leading effect of S&P 500 fossil-fuel free index returns. The stock returns are leading the Twitter-based economic uncertainty as stock markets are an indicator of the health of the economy where sharp reduction in stock prices results in higher uncertainty. Moreover, stock returns move away from fundamental values during financial turmoil, increasing volatility (Setiawan et al., 2021). However, stock returns and uncertainty relationship is complex and depend on different political and macroeconomic factors (Hoque et al., 2019).

The Figure 1b shows the positive co-movement between S&P 1200 global fossil-fuel free index returns and Twitter-based economic uncertainty at 16-256 days frequency bands (medium-term investment horizons) and negative co-movement (↘) at 300-400 days frequency bands in COVID-19 pandemic.

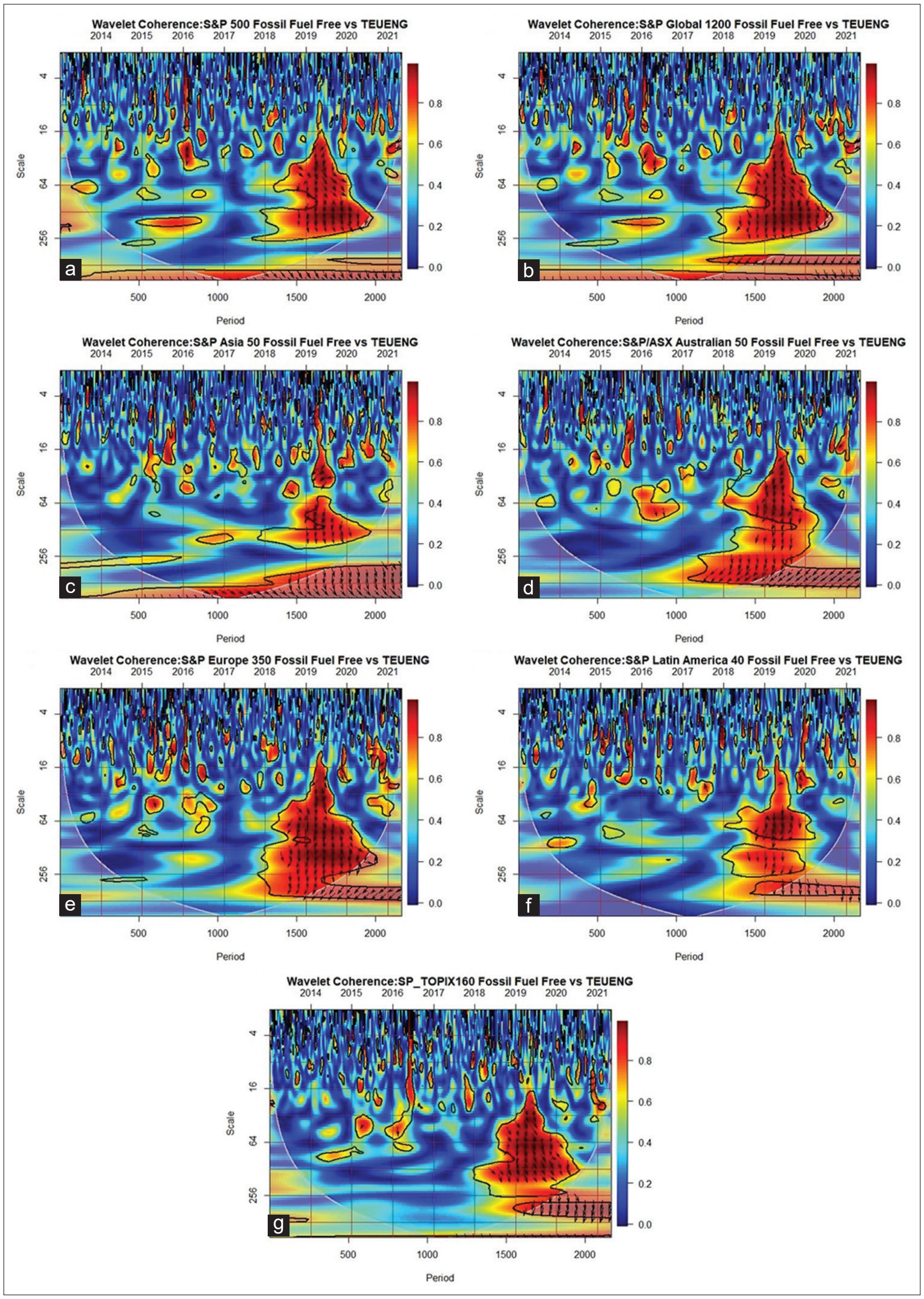
Similarly, Figure 1c indicates the negative co-movement of S&P Asia 50 fossil-fuel free index and Twitter economic uncertainty at 4-12 and 18-40 days frequency bands in the COVID-19 pandemic which is indicated by (↙) arrows. This co-movement turns to positive for long-term investors at 300-512 days frequency bands with right-ward directed arrows (↘) which shows that investors in fossil-fuel-free indices in Asia can get higher returns during the COVID-19 pandemic.

Conversely, in Figure 1d, we can see the negative co-movement of the S&P ASX Australian 500 fossil fuel-free index and Twitter economic uncertainty in the COVID-19 pandemic (↙) in 16-400 days frequency bands. These findings show that fossil-fuel-free indices in Australia did not perform well during COVID-19 when Twitter economic uncertainty is higher than global indices. A similar trend is observed in Figure 1e, which displays the negative co-movement of S&P350 Europe fossil-fuel free index returns and Twitter economic uncertainty at 16-300 days frequeny bands with the leading effect of fossil-fuel index returns in the COVID-19 pandemic. Figure 1f also displays the negative co-movement of S&P Latin America 400 fossil-fuel free index returns and Twitter economic uncertainty during the COVID-19 pandemic but the co-movement turns to positive during the Russia-Ukraine war at 256-300 days frequency bands.

Finally, wavelet coherence in Figure 1g displays strong and positive co-movement of the S&P TOPIX 160 fossil-fuel free index and Twitter economic uncertainty at 16-256 days frequency bands (medium-term) during COVID-19 pandemic (↘) and it turns to negative during Russia-Ukraine war for long-term investors.

Overall, these findings suggest that during the COVID-19 pandemic, the global (S&P Global 1200), US (S&P 500), and Japanese (S&P TOPIX160) fossil-fuel-free equity indices provide higher returns to medium-term investors. While, the US (S&P 500), Asia (S&P Asia 50), and Latin America (S&P Latin America 40)

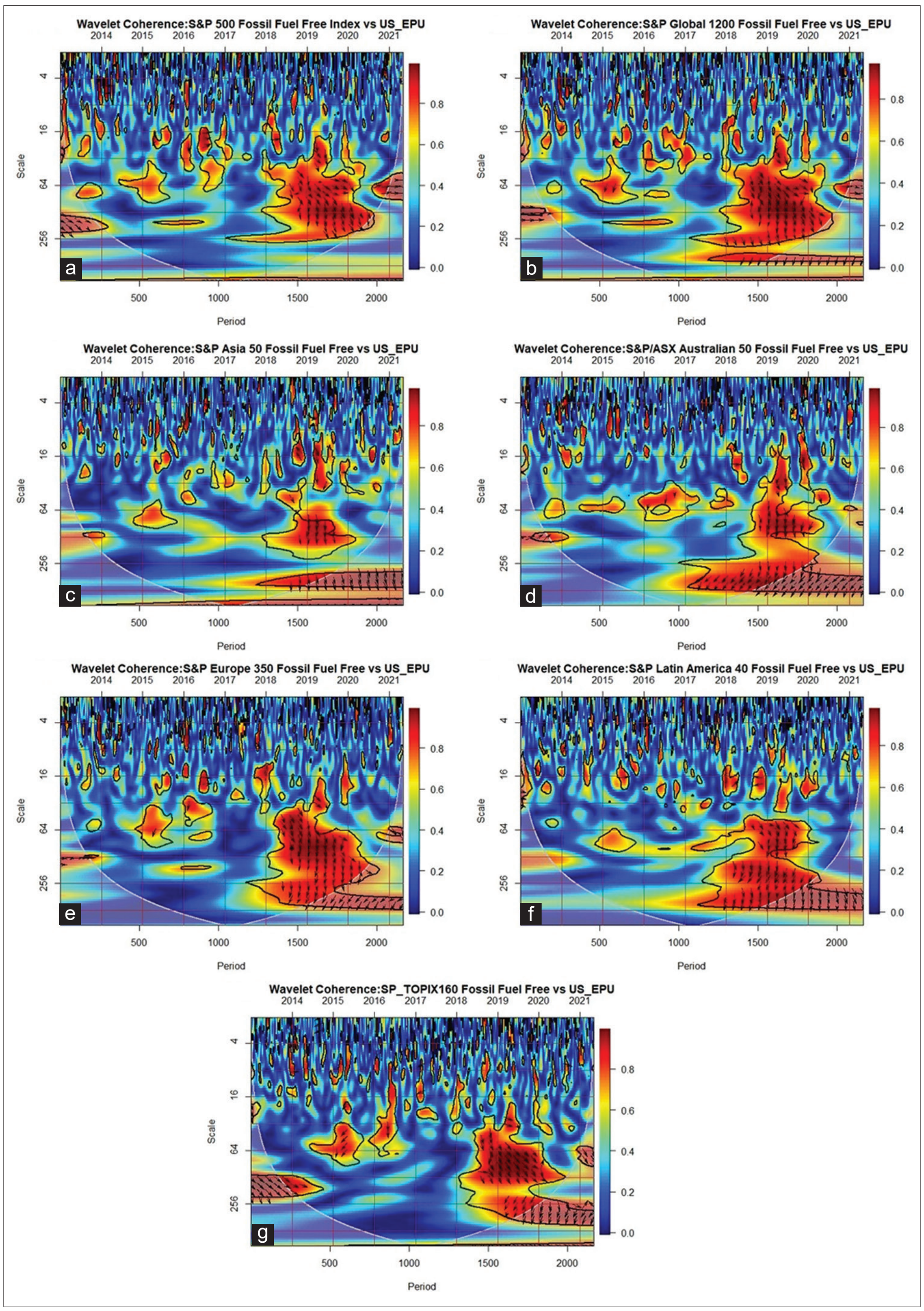
Figure 3: (a-g) S&P Fuel free indices and twitter economic uncertainty. Presents the results of wavelet coherence between returns of S&P fossil-fuel-free indices and Twitter economic uncertainty which is the second series. The color heat map displays the intensity of co-movement which ranges from blue (close to zero) to red to high (close to one). The direction of co-movement between two-time series x and y in the wavelet coherence plot is explained with arrows. Where, rightward-directed arrows →:x" and "y" show in-phase (Positive co-movement), leftward-directed arrows ←:x" and "y" indicate an anti-phase relationship (Negative co-movement)." While downward arrows indicate ↓: x" leading "y" by "90° (First Series is Leading) and ↑: y" leading "x" by "90° (Second Series is Leading). Source: Datastream database



fossil-fuel-free equity indices provide higher returns to long-term investors. Therefore, both medium and long-term energy market investors can diversify their portfolios by investing in these equity indices as they perform well during periods of higher economic uncertainty. The findings are consistent with prior studies that show the outperformance of fossil-fuel-free indices during financial turmoil (Al Ayoubi and Enjolras, 2022; Heaps et al., 2016; Henriques and Sadorsky, 2018; Hunt and Iber, 2019; Yook and Hooke, 2020).

There exist a few reasons behind these outcomes. For instance, Twitter is a platform where individuals express their opinions and share information. By analyzing the sentiment of tests related to economic uncertainty, investors can gauge market sentiment and make investment decisions accordingly. If there is a significant increase in negative sentiment and concerns about economic uncertainty, investors may seek safer and more stable investments, such as fossil fuel-free stocks. Next, increased economic uncertainty on Twitter may lead to a shift in investor preferences. Investors may become more risk-averse and seek investments that are considered more sustainable and resilient in the face of economic downturns. Fossil fuel-free stocks, which typically include companies focused on renewable energy, clean technology, and environmentally friendly practices, may attract increased attention as investors prioritize sustainability and long-term stability. Likewise, economic uncertainty can arise due to changes in regulations or policies that affect certain industries. TIets discussing potential regulatory changes or government actions can create uncertainty and volatility in the market. Fossil fuel-free stocks may benefit if there is a perception

Figure 4: (a-g) S&P fuel free indices and twitter economic uncertainty. The results of wavelet coherence betIen returns of S&P fossil-fuel-free indices (S&P 500 Fossil Fuel Free Index, S&P 1200 Global Fossil Fuel Free Index, S&P Asia 50 Fossil Fuel Free Index, S&P ASX 50 Fossil Fuel Free Index, S&P EU 350 Fossil Fuel Free Index, S&P LAT40 Fossil Fuel Free Index, and S&P TOPIX160 Fossil Fuel Free Index) as first series and US newspaper-based economic policy uncertainty is second series. The color heat map displays the intensity of co-movement which ranges from blue (close to zero) to red to high (close to one). The direction of co-movement betIen two time series x and y in a wavelet coherence plot is explained with arrows. Where, rightward directed arrows →:x" and "y" show in-phase (Positive co-movement), leftward directed arrows ←:x" and "y" indicate anti-phase relationship (Negative co-movement)." While downward arrows indicate ↓: x" leading "y" by "90° (First Series is Leading) and ↑: y" leading "x" by "90° (Second Series is Leading). Source: Datastream 4 database



that stricter regulations or policies favoring renewable energy and clean technologies are likely to be implemented. Such expectations can drive investor interest and increase the returns of these stocks. Also, Environmental, Social, and Governance (ESG) investing has gained significant traction in recent years, with investors increasingly considering sustainability factors in their decision-making process. Twitter-based discussions on economic uncertainty may further amplify the importance of ESG considerations. Fossil fuel-free stocks, which are often associated with positive environmental and social impacts, may experience increased demand as investors seek investments aligned with their values and sustainability goals.

5. ROBUSTNESS ANALYSIS

Figure 4 (2a-g) test the co-movement of fossil-fuel-free indices and newspaper-based US economic policy uncertainty index at time and frequency domains for robustness purposes. Figure 2a displays the positive co-movement of the S&P 500 fossil-fuel free index and US economic policy uncertainty at 32-256 days frequency bands before COVID-19, during the COVID-19 pandemic, and in the Russia-Ukraine war, which shows that during turbulent economic conditions, this index provides higher returns for medium-term investors. The S&P 1200 fossil-fuel-free index in Figure 2b also shows the same trend but its co-movent is negative for long-term investors at 300 days frequency band. The S&P Asia 50 and S&P/ASX Australian 50 fossil fuel-free indices in Figure 2c and d display the negative co-movement that is aligned with our previous findings by using Twitter economic uncertainty as a proxy. These findings show that these equity indices' performance is not higher, and investors in Asia and Australia cannot get higher returns by using these indices in their portfolios.

The results of S&P 350 Europe and economic policy uncertainty, in Figure 2e, shows the positive co-movement at the 16-128 days frequency band during the COVID-19 pandemic and we can spot the positive co-movement in the 64-100 days frequency bands during the Russia-Ukraine war. These findings show that European fossil-fuel-free equity indices perform well during the COVID-19 crisis and during the war and investors can hedge the uncertainties by using these indices. Conversely, in Figure 2f, Latin America 40 fossil-fuel free index and US economic policy uncertainty show the negative co-movement aligned with our earlier findings using the Twitter economic uncertainty index as a proxy. Finally, Figure 2g shows the positive co-movement of the S&P TOPIX 160 fossil-fuel free index and US economic uncertainty at 32-140 days frequency bands during the COVID-19 pandemic (↘) also positive at 64-100 days frequency bands. These findings show that Japanese fossil-fuel-free indices can be used to hedge the uncertainty in the US market, and investors in the US market can use these assets to hedge the risks during the COVID-19 pandemic.

Overall, almost similar findings are found of fossil-fuel-free indices by using Twitter economic uncertainty and US newspaper-based economic policy uncertainty, showing that these indices perform better during the COVID-19 pandemic when uncertainty unexpectedly increased. Risk-averse investors can hedge the uncertainty by investing in fossil-fuel-free companies.

6. CONCLUSION

Given the criticality of environmental degradation, global warming, and/or climate change, the entire world strives to shift toward renewable energy. However, the transition to renewable energy entails an enormous volume of financing. Parallel to this, economic uncertainty and exogenous shocks such as the COVID-19 outbreak and the Russia-Ukraine war make the decision-making on renewable energy financing immensely difficult. Hence, it is appropriate to explore how economic uncertainty impacts green energy financing, especially during the COVID-19 and the Russia-Ukraine war.

Based on this backdrop, this study investigates the relationship between fossil-fuel-free indices and economic uncertainty at time and frequency domains. The wavelet coherence approach is applied to data of fossil-fuel-free indices from 7th January 2013 to 17th June 2022 gathered from the Datastream database. This study selected fossil-fuel-free indices because of their role in the transition from investments in fossil fuels and the energy market towards sustainable investments and Twitter-based economic uncertainty is used because retail investors and other stakeholders decide about their investments by looking at sentiment on Twitter and newspapers (Behera and Rath, 2022; Enamul Hoque et al., 2019; Gök et al., 2022).

The findings show that fossil-fuel-free indices perform better during the COVID pandemic when traditional financial assets sharply lose value at that time global, US, and Japanese fossil-fuel-free equity indices give higher returns for medium and long-term investors. For robustness, US newspaper-based economic uncertainty is also utilised as a proxy and similar findings have surfaced compared to Twitter's economic uncertainty.

Overall, the findings show that fossil-fuel-free indices help investors maximize their returns at a given level of risk. The selection of constrained or screened stocks did not limit the portfolio returns. I suggest investments in fossil-fuel-free indices to reduce reliance on fossil fuels and diversify their investments, especially during the COVID-19 pandemic. These investments also help the investors to move from fossil fuel to clean energy investments that align with stakeholders' interests and support the fossil-fuel divestment campaigns to mitigate the adverse impacts of fossil fuels on the environment.

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