Dias, Rui; Galvão, Rosa Morgado; Cruz, Sandra et al.

Article

Testing the diversifying asset hypothesis between clean energy stock indices and oil price

International Journal of Energy Economics and Policy

Reference: Dias, Rui/Galvão, Rosa Morgado et. al. (2024). Testing the diversifying asset hypothesis between clean energy stock indices and oil price. In: International Journal of Energy Economics and Policy 14 (6), S. 295 - 302.
https://www.econjournals.com/index.php/ijeep/article/download/16988/8316/39974.
doi:10.32479/ijeep.16988.

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2024, 14(6), 295-302.

Testing the Diversifying Asset Hypothesis between Clean Energy Stock Indices and Oil Price

Rui Dias[1], Rosa Galvão[2]*, Sandra Cruz[3], Mohammad Irfan[4], Paulo Alexandre[2], Sidalina Gonçalves[2], Nuno Teixeira[2], Cristina Palma[2], Liliana Almeida[2]

[1]Instituto Politécnico de Setúbal, Escola Superior de Ciências Empresariais, Setúbal, Portugal and ESCAD-Instituto Politécnico da Lusofonia, Lisboa, Portugal, [2]Instituto Politécnico de Setúbal, Escola Superior de Ciências Empresariais, Setúbal, Portugal, [3]ESCAD - Instituto Politécnico da Lusofonia, Lisboa, Portugal; and CEFAGE- University of Algarve, Campus de Gambelas, 8005-189 Faro, Portugal, [4]School of Business and Management, Christ University, Lavasa, Pune, India. *Email: rosa.galvao@esce.ips.pt

Received: 06 June 2024 **Accepted:** 17 September 2024 **DOI:** https://doi.org/10.32479/ijeep.16988

ABSTRACT

In theory, geopolitical risk and political uncertainty can directly affect energy markets. Fluctuations lead to the cost of clean energy sources as they compete with traditional energy. The purpose of this study is to analyse financial integration and test the diversifying asset hypothesis between clean energy indices, specifically the Clean Energy Fuels (CLNE), Nasdaq Clean Edge Green Energy (CELS), S&P Global Clean Energy (SPGTCLEN), TISDALE Clean Energy (TCEC.CN), Wilderhill (ECO) and West Texas Intermediate (WTI) stock indices, over the period from 1 January 2018 to 23 November 2023. Analysing the results reveals a scenario where most of the clean energy indices show cointegration with each other, indicating long-term relationships that reflect common trends in the clean energy sector. However, the relative independence of the WTI suggests that Oil still acts as an important and potentially diversifying external factor for investors focused on sustainable energy. Structural breaks in 2021 and 2022 in several indices point to significant events that have altered market dynamics, possibly including changes in environmental policies, technological innovations and the impacts of the COVID-19 pandemic. The cointegration evidence and structural breaks provide valuable information for building investment portfolios. Investors can consider the WTI to diversify portfolios dominated by clean energy assets, taking advantage of Oil's relative independence. On the other hand, the high correlation between clean energy indices suggests that, within this sector, diversification options are more limited, requiring careful analysis of the specific characteristics of each index and the macroeconomic forces affecting them.

Keywords: Clean Energy Indices, WTI, Financial Integration, Long Memories, Portfolio Diversification
JEL Classifications: F30; G15

1. INTRODUCTION

Investments in companies that promote sustainable practices are gaining worldwide popularity, driven by the growing concern for environmental sustainability. One sector in particular that is rapidly expanding is clean energy, which is focused on renewable sources such as solar, wind, hydroelectric, geothermal, and biomass. At the same time, there have been significant advances in the technology of these clean energies, especially solar and wind power, which have become more accessible and efficient, positioning them as viable alternatives to fossil fuels. In addition to the environmental benefits, there is growing recognition of the positive economic impacts of clean energy, including creating jobs and stimulating local economic development (Dias et al., 2023; Dias et al., 2023; Dias et al., 2023a)

Recently, global energy prices have been significantly impacted by the COVID-19 pandemic and the ongoing war between Russia and Ukraine, resulting in substantial changes in market behaviour. The initial pandemic outbreak led to a drastic reduction in energy consumption due to the health measures implemented to contain the virus, which resulted in lower prices and reduced production. During this period, tensions between the main oil producers, such as Saudi Arabia and Russia, emerged due to the continuous price drop. Saudi Arabia proposed production cuts to stabilise the market, while Russia disagreed, exacerbating geopolitical and economic tensions. With the post-pandemic economic upturn in 2021, energy demand has surpassed supply, pushing prices and generating instability in the global energy market. The energy crisis intensified with the outbreak of war between Russia and Ukraine in 2022, when Russia interrupted energy supplies to European countries, causing an energy crisis on the continent and increasing the volatility of energy prices on the international market, reflecting the significant effects of geopolitical issues on the global energy economy (Chambino et al., 2022; Dias et al., 2020, 2021, 2024; Dias et al., 2023b; Dias and Irfan, n.d.; Santana et al., 2023; Teixeira et al., 2022; Elgayar et al., 2024).

A significant gap in the existing literature on this topic is the lack of studies investigating the dynamics of financial integration and the characterisation of specific diversifying assets within the clean energy sector, considering multiple indices and including the oil price West Texas Intermediate (WTI). Although there is growing awareness of the importance of clean energy and its impact on financial markets, few studies have comprehensively addressed how these clean energy indices relate to each other and to an external asset such as WTI throughout periods of economic instability and geopolitical change, as observed during the COVID-19 pandemic and the Russia-Ukraine crisis. Furthermore, analysing the ability of certain clean energy indices to act as diversifying assets in investment portfolios has not yet been extensively explored, especially considering the diversity of technologies and policies that can influence these markets. Therefore, more in-depth studies examining these complex interactions are needed to provide more robust and sustainable investment strategies in the context of the global energy transition.

The paper is organised as follows: Section 2 reviews related studies on integration and diversifying clean energy assets. Section 3 describes the data and methodology used to address the research questions. Section 4 introduces the data analysis and provides interpretations of the results. Finally, Section 5 offers conclusions based on the results reported in the paper.

2. LITERATURE REVIEW

Politics and the global financial markets increasingly emphasise the transition to cleaner and more sustainable energy sources. This movement reflects a growing concern for environmental sustainability and a recognition of the significant impacts that clean energy can have on global financial markets. Despite the increase in awareness and the implementation of favourable policies, there is a notable lack of academic literature investigating the dynamics of financial integration between specific indices in the clean energy sector. In particular, understanding how these indices interact with each other and with external assets, such as the price of West Texas Intermediate (WTI) oil, is limited. This research aims to fill this gap by comprehensively and systematically exploring the financial interactions between multiple clean energy indices and the WTI. In doing so, it is hoped to provide valuable insights for investors, policymakers and academics interested in sustainable and resilient investment strategies in the context of global energy transition.

2.1. Related Studies

The authors (Bondia et al., 2016) and (Dutta, 2017) studied the synchronisations between oil prices, technology, financial variables and clean energy stock indices. (Bondia et al., 2016) show that the share prices of alternative energy companies are affected by the share prices of technology companies, Oil and interest rates in the short term. The author (Dutta, 2017) reveals that clean energy stock market returns are susceptible to crude oil volatility shocks (OVX). Thus, oil market uncertainty, as measured by the OVX, plays a crucial role in modelling the volatility of renewable energy stock returns. Furthermore, a strong indication is found that the OVX provides additional information beyond what is contained in the historical volatilities of stock returns.

Furthermore, the magnitude of the OVX effect is much larger than that of the realised variance of WTI oil spot prices. Additionally, the authors (Ferrer et al., 2018) show that crude oil prices do not appear as one of the main drivers of the stock market performance of renewable energy companies in the short or long term, which suggests a decoupling of the alternative energy industry from the traditional energy market. While authors (Wang and Cai, 2018) show that the carbon market has the power to explain the movement of the share prices of clean energy companies, and the share prices of clean energy companies also affect the carbon market. Later, the authors (Ren and Lucey, 2022) investigated the integration of clean energy indices against two distinct types of cryptocurrencies based on their energy consumption levels, labelled "dirty" and "clean." Statistical evidence shows that clean energy is not a direct hedge for either type. However, it acts as at least a weak safe harbour for both in extremely pessimistic markets. Furthermore, clean energy is more likely to be a safe haven for dirty cryptocurrencies than clean cryptocurrencies during increased uncertainty.

In complementing this, Annamalaisamy and Vepur Jayaraman (2024) examined the integration of cryptocurrencies and the stock, sustainability, renewable energy and crude oil indices from 2015 to 2021. The empirical results show no integration on the short-term scales, stronger integration on the medium-term scales, especially during COVID-19, and weaker heterogeneous associations on the long-term scales. Complementary to this, the authors Dias et al. (2023) evaluated the level of integration between clean energy stock indices and cryptocurrencies. The empirical findings show that clean energy stock indices can offer a viable safe harbour for dirty energy cryptocurrencies. However, the precise associations differ depending on the cryptocurrency examined.

More recently, (Dong and Huang, 2024) examined the dynamic relationship between oil price volatility, fintech, and clean energy stocks from June 2013 to December 2022. The results reveal significant associations between the variables examined. Fintech stocks positively influence clean energy stocks. These results suggest that the rise of fintech acts as a catalyst for sustainable investment and restores investor confidence in the financial services sector. Similarly, the authors (Tedeschi et al., 2024) analysed the effect of climate policy uncertainty (CPU) on the stock market and clean energy indices in the European context. The empirical results show that CPU shocks significantly affect financial indices. In response to heightened climate risk, returns on clean energy stocks (crude Oil) increase (decrease). In addition, the COVID-19 pandemic is a relevant turning point in CPU dynamics. These results offer important implications for European investors and policymakers in the context of the European climate-energy crisis.

Given the existing literature, it is pertinent to study the integration between clean energy stock indices and Oil, which is crucial for understanding the energy transition, helping to diversify portfolios, and informing effective policies and regulations. It is also vital for predicting and mitigating economic risks, incentivising technological innovation, and developing strategies to combat climate change. In addition, this analysis provides insights into sustainable practices and the evolution of corporate responsibilities, reveals price dynamics and the global interdependence of markets, and supports the long-term planning of companies and governments, promoting a transition to a more sustainable and resilient future.

3. MATERIALS AND METHODS

This research was developed in different stages. Firstly, to characterise the sample, the main descriptive statistical measures and the Jarque and Bera (1980) adherence test, which postulates the normality of the data, were used. The panel unit root tests of Levin et al., (2002) were used to validate the assumption of stationarity of the time series. The Gregory and Hansen (1996a, 1996b) methodology was applied to verify the integration or segmentation of the WTI with the clean energy stock indices since the study was conducted during a turbulent global economy period. The Gregory and Hansen (1996a, 1996b) methodology is robust in very turbulent periods in the financial markets as the authors generalise the usual cointegration tests by considering that the cointegration vector changes at an unknown date. The authors analysed four integration models. The first model incorporates a change of level (Level):

$$y_t = \mu_1 + \mu_2 D_t + \beta' x_t + \mu_t \qquad t = 1,\ldots,T \tag{1}$$

Where x_t is a vector I(1) of dimension k, μ_t is I(0), μ_1 is the independent term before the change, μ_2 is the change in the independent term after the break and is a dummy variable.

The second model includes a time trend (Trend):

$$y_t = \mu_1 + \mu_2 D_t + \alpha t + \beta'^{x_t} \qquad t = 1,\ldots,T \tag{2}$$

In this model, o μ_1 is the independent term before the change in structure and is the change in the independent term after the break. Compared to the previous one, this model introduces a regime change (Regime).

$$y_t = \mu_1 + \mu_2 D_t + \alpha t + \beta'^{x_{t+} \beta'_2 x_t D_t} + \mu_t \qquad t = 1,\ldots,T \tag{3}$$

A possible change in the structure allows the inclination vector to change as well. This allows the equilibrium relationship to move in parallel with the level. The authors call this third model the regime shift model.

Finally, the fourth model is introduced, which complements the previous ones. The authors add the possibility of a change in structure in a model with a segmented time trend (Regime and Trend):

$$y_t = \mu_1 + \mu_2 D_t + \alpha t + \alpha_2 t D_t + \beta'_1 x_t + \beta'_2 x_t D_t + \mu_t \qquad t = 1,\ldots,T \tag{4}$$

Here, both μ_1 and μ_2 are the terms already presented in the previous models. α_1 represents the cointegration of the slope coefficients and represents the change in the slope of the coefficients.

4. RESULTS AND DISCUSSION

4.1. Sample Characterisation

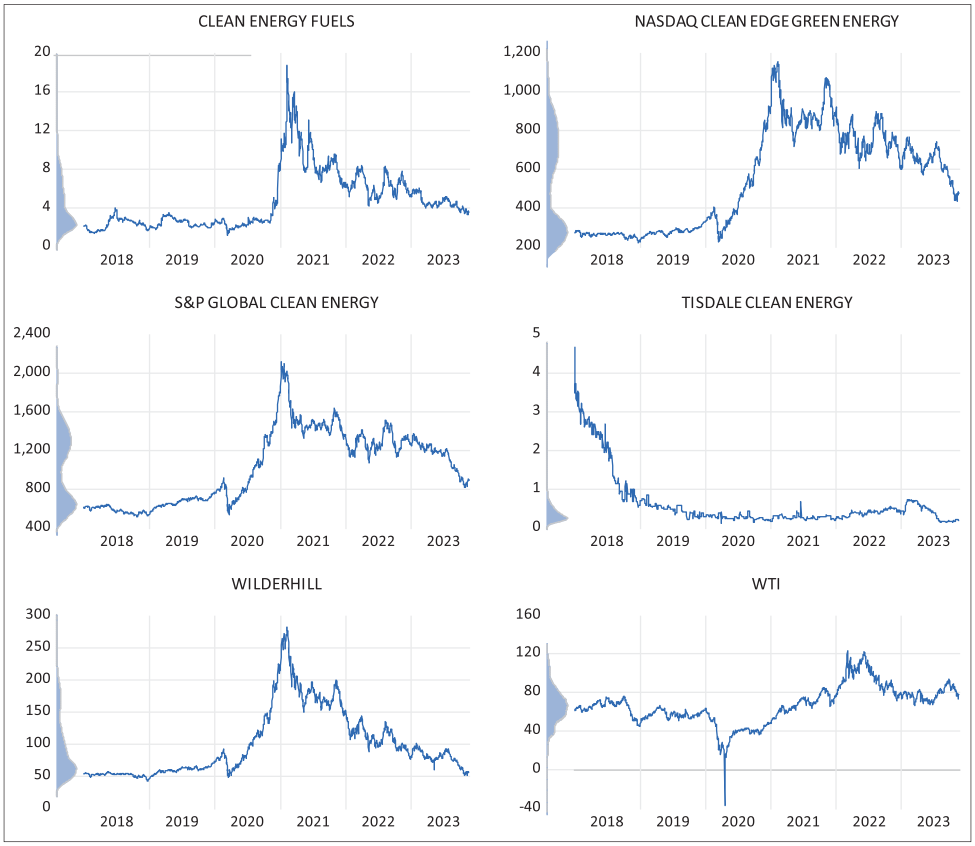
Figure 1 illustrates the evolution, in levels, of the Clean Energy Fuels (CLNE), Nasdaq Clean Edge Green Energy (CELS), S&P Global Clean Energy (SPGTCLEN), TISDALE Clean Energy (TCEC.CN), Wilderhill (ECO) and West Texas Intermediate (WTI) stock indices over the period from 1 January 2018 to 23 November 2023.

Throughout this period, there has been clear instability in the clean energy markets, particularly in January, February and March 2020. This instability coincides with the start of the COVID-19 pandemic, which has caused great volatility in several financial markets. However, it is in 2021 that we see significant structural breaks in the clean energy indices, suggesting a possible correlation with the bilateral agreements between China and the US. These agreements may have directly influenced investor confidence and, consequently, the movements of the indices. These indices reflect the complex and interconnected dynamics of the global clean energy market, which is influenced not only by domestic economic and political issues but also by international agreements and global events. Analysing the indices over time makes it possible to identify patterns of behaviour and possible trigger factors, offering valuable insights for investors and analysts in the sector.

Table 1 shows the main descriptive statistics for the Clean Energy Fuels (CLNE), Nasdaq Clean Edge Green Energy (CELS), S&P Global Clean Energy (SPGTCLEN), TISDALE Clean Energy (TCEC.CN), Wilderhill (ECO) and West Texas Intermediate (WTI) stock indices for the period from 1 January 2018 to 23 November 2023.

The mean returns of the indices are predominantly positive, except for the Canadian TISDALE Clean Energy index (TCEC. CN), which had a mean return of -0.00211. The index with the highest standard deviation, indicating greater volatility and risk, is TISDALE Clean Energy, with a value of 0.0986. In contrast, the S&P Global Clean Energy has the lowest volatility, with a standard deviation 0.0170. On the other hand, the indices have asymmetric values far from zero, suggesting asymmetric

Figure 1: Evolution, in levels, of the financial markets analysed, from 1 January 2018 to 23 November 2023



Note: Data processed by the authors (software: Eviews12)

Table 1: Descriptive statistics, in returns, of the clean energy and WTI indices from 1 January 2018 to 23 November 2023

	Clean energy fuels	NASDAQ	S&P global clean energy	TISDALE clean energy	Wilderhill	WTI
Mean	0.00037	0.00041	0.00028	−0.00211	5.87e-05	0.00062
SD	0.0478	0.0236	0.0170	0.0986	0.0271	0.03268
Skewness	0.6158	−0.2979	−0.3825	1.4993	−0.14818	0.6171
Kurtosis	15.2792	7.0279	10.3960	34.6826	11.4766	26.3458
Jarque-Bera	9753.33***	1061.75***	3540.63***	64860.48***	4607.25***	35002.21***

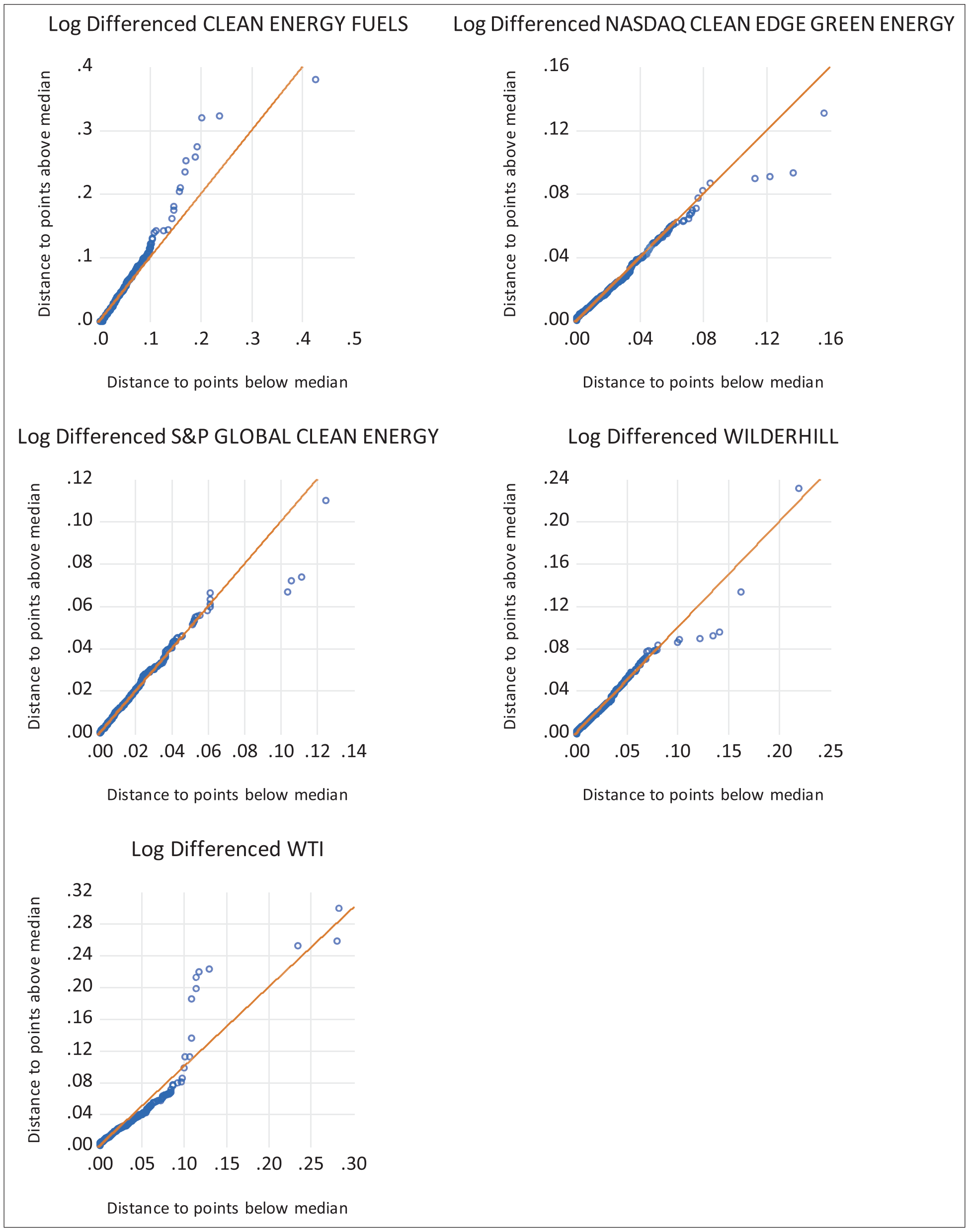
Source: Own elaboration. Note: Data processed by the authors (software: Eviews12). The asterisks *** represent the rejection of the null hypothesis at a significance level of 1%

distributions. The NASDAQ Clean Edge Green Energy (-0.2979), S&P Global Clean Energy (-0.3825) and Wilderhill (-0.14818) indices have negative asymmetries. This indicates that the distributions of these indices have longer tails to the left of the mean, reflecting a greater frequency of low or negative returns. The implication is that investors may face greater risks of extreme losses in these markets. The kurtosis values for all the indices differ significantly from the reference value 3. The TISDALE Clean Energy index stands out with a kurtosis of 34.6826, characterising a leptokurtic distribution with heavier tails and frequent extreme values. This implies that although the mean returns may be positive, extreme events (outliers) are more likely, increasing the uncertainty and risk associated with these investments. Corroboratively, all the returns time series showed significant deviations from the normality hypothesis. The Jarque-Bera test validates these results, indicating that the return distributions do not follow a normal distribution. This non-normality implies that traditional asset pricing models, which assume normality, may not be suitable for analysing these indices. Investors should consider alternative methods that consider the higher probability of extreme events and the asymmetry of distributions.

The statistics indicate that clean energy stock markets are characterised by high volatility, asymmetric risks and a propensity for extreme events. Investors should be aware of these characteristics when designing investment and risk management strategies. The non-normality of the distributions suggests the need for more robust models and advanced techniques to correctly assess the risk and return of these indices, as well as continuous monitoring of market conditions to mitigate possible extreme losses.

Figure 2 shows the Q-Q Plots of the Clean Energy Fuels (CLNE), Nasdaq Clean Edge Green Energy (CELS), S&P Global Clean Energy (SPGTCLEN), TISDALE Clean Energy (TCEC.CN), Wilderhill (ECO) and West Texas Intermediate (WTI) stock indices from 1 January 2018 to 23 November 2023. The graphical analysis shows that all the indices distributions are asymmetrical, as evidenced by the deviations of the points from the 45° line. These deviations indicate that the time series of the indices do not follow

Figure 2: Q-Q Plots, in returns, of the WTI and clean energy indices from 1 January 2018 to 23 November 2023



Note: Data processed by the authors (software: Eviews12)

a normal distribution, exhibiting irregular asymmetry and kurtosis. This behaviour has important implications for econometric modelling, suggesting that methods that assume normality may not be suitable. Given this scenario, the Gregory and Hansen (1996a, 1996b) model was used, which is suitable for time series with possible regime shifts. This model allows structural changes in the data to be identified and adjusted, offering a more robust and accurate analysis. The Gregory and Hansen model extends classical cointegration tests to allow for a structural break in the long-term relationship between time series.

It was essential to analyse the stationarity of the time series to apply the econometric methods that would allow answering the research questions. In this context, panel unit root tests were performed, specifically the Levin et al., (2002) test, applied to the Clean Energy Fuels (CLNE), Nasdaq Clean Edge Green Energy (CELS), S&P Global Clean Energy (SPGTCLEN), TISDALE Clean Energy (TCEC.CN), Wilderhill (ECO) and West Texas Intermediate (WTI) stock indices, from 1 January 2018 to 23 November 2023.

The results of these tests indicated that the original price time series had unit roots, suggesting non-stationarity. Logarithmic transformation in first differences was necessary to achieve stationarity. After this transformation, the unit root tests of Levin et al., (2002) showed that the null hypothesis of a unit root was rejected for all the indices evaluated. These results validate the assumption of stationarity necessary for applying subsequent econometric techniques. The logarithmic transformation in first differences effectively stabilised the variance and removed the trend in the time series, allowing for more robust and reliable analyses (Table 2).

4.2. Cointegration tests: Gregory and Hansen

This section explains the application of the Gregory and Hansen (1996a, 1996b) test due to the presence of structural breaks in the time series analysed.

Firstly, given that the date on which the break in structure occurred is unknown, the break in structure and the respective date will be calculated; secondly, the values obtained from the three statistical tests, ADF, Z_t e Z_a, designed to test the null hypothesis that postulates non-integration against the alternative that postulates integration (long-term relations between financial markets) will be assessed.

The Gregory and Hansen (1996a, 1996b) test is a robust approach to detecting cointegration between time series with structural breaks and is highly relevant for analysing long-term relationships in the presence of structural changes. The results presented in Table 3 provide detailed insights into the cointegration between the clean energy stock indices and the West Texas Intermediate (WTI) oil price index from 1 January 2018 to 23 November 2023.

The Clean Energy Fuels Index (CLNE) shows cointegration with all its peers, indicating a long-term relationship between this index and the other clean energy indices and the price of Oil. Most structural breaks occurred in January 2021, except for the integration with WTI, which shows a break on 23 December 2020. This suggests that specific events around these dates significantly influenced these time series' relationships. The generalised cointegration of CLNE with other indices indicates that this asset does not have diversification characteristics, as it tends to move in tandem with the other clean energy sector indices and the WTI.

Table 2: Summary of the Levin et al., (2002) unit root test applied to the clean energy indices and WTI from 1 January 2018 to 23 November 2023.

Null Hypothesis: Unit root (common unit root process)							
Method				**Statistic**		**Prob.****	
Levin, Lin and Chu t*				−108.75		0.0000	
Intermediate results on D (UNTITLED)							
Series	**2nd Stage**	**Variance**	**HAC of**		**Max**	**Band-**	
	Coefficient	**of Reg**	**Dep.**	**Lag**	**Lag**	**width**	**Obs**
D (CLEAN ENERGY FUELS)	−0.9611	0.1009	0.0009	2	23	216	1535
D (NASDAQ CLEAN EDGE GREEN ENERGY)	−1.0008	237.7862	8.3987	0	23	58	1537
D (S&P GLOBAL CLEAN_ENERGY)	−0.8457	385.6316	10.7187	0	23	71	1537
D (TISDALE CLEAN ENERGY)	−2.2062	0.0031	0.0018	9	23	5	1528
D (WILDERHILL)	−0.9148	10.6191	0.16471	1	23	128	1536
D (WTI)	−1.3457	6.2696	0.0851	1	23	156	1536
	Coefficient	**t-Stat**	**SE Reg**	**mu***	**sig***		**Obs**
Pooled	−0.9934	−69.9971	1.011	−0.5	0.5		9209

Source: Own elaboration. ** Probabilities are computed assuming asymptotic normality

Table 3: Summary table of integration tests, with Gregory and Hansen (1996a, 1996b) structure breaks, from 1 January 2018 to 23 November 2023

Markets	Test	Statistic t	Method	Lags	Break	Results
Clean Energy Fuels – Nasdaq Clean Edge Green Energy	ADF	−5.13**	Regime	4	08/01/2021	Integration
Clean Energy Fuels – S&P Global Clean Energy	Zt	−5.76***	Regime	5	13/01/2021	Integration
Clean Energy Fuels - WILDERHILL	Zt	−6.83***	Regime	4	08/01/2021	Integration
Clean Energy Fuels−WTI	Zt	−5.76***	Trend	3	23/12/2020	Integration
S&P Global Clean Energy – Nasdaq Clean Edge Green Energy	Za	−43.37*	Regime	0	15/02/2021	Integration
S&P Global Clean Energy – Clean Energy Fuels	Zt	−4.90*	Regime	4	09/02/2021	Integration
S&P Global Clean Energy−WILDERHILL	ADF	−4.84	Regime	4	18/03/2022	Integration
S&P Global Clean Energy−WTI	Zt	−4.46	Trend	2	No break	Segmented
WILDERHILL – Nasdaq Clean Edge Green Energy	Za	−42.73*	Regime	0	06/08/2021	Integration
WILDERHILL – Clean Energy Fuels	ADF	−4.93*	Trend	4	18/03/2022	Intregation
WILDERHILL−S&P Global Clean Energy	ADF	−4.81*	Trend	4	18/03/2022	Integration
WILDERHILL−WTI	Zt	−4.20	Trend	0	No break	Segmented
Nasdaq C. E. Green Energy – WILDERHILL	ADF	−4.86*	Regime	0	16/07/2021	Integration
Nasdaq C. E. Green Energy – Clean Energy Fuels	Zt	−4.22	Regime	4	No break	Segmented
Nasdaq C. E. Green Energy−S&P Global Clean Energy	Zt	−4.27	Trend	0	No break	Segmented
Nasdaq C. E. Green Energy−WTI	Zt	−4.22	Trend	2	No break	Segmented
WTI – WILDERHILL	ADF	−4.49	Trend	1	No break	Segmented
WTI – Clean Energy Fuels	ADF	−4.81*	Trend	1	25/12/2020	Integration
WTI−S&P Global Clean Energy	ADF	−4.16	Trend	1	No break	Segmented
WTI−Nasdaq C. E. Green Energy	ADF	−4.02	Trend	1	No break	Segmented

Data processed by the authors (software: Eviews12). The critical values may be found in the paper by Gregory and Hansen (1996a). The critical values for Trend are: ADF and Z_t: −5.45 (1%); −4.99 (5%); −4.72 (10%). For the Z_a parameter, the critical values are: −57.28 (1%); −47.96 (5%); −43.22 (10%). The critical values for regime are: ADF e Z_t são: −5.47 (1%); −4.95 (5%); −4.68 (10%). For the Z_a parameter, the critical values are: −57.17 (1%); −47.04 (5%); −41.85 (10%). The asterisks ***, **, * indicate the significance of the statistics at 1%, 5% and 10% respectively

The S&P Global Clean Energy (SPGTCLEN) and Wilderhill (ECO) indices show cointegration with other sustainable energy indices. However, they show some degree of isolation from the WTI. The structural breaks identified in 2021 and 2022 suggest that specific factors in those years impacted the long-term relationship between these indices. This isolation relative to WTI implies that the oil price index can be considered a diversifying asset in portfolios that include SPGTCLEN and ECO. The relative independence of WTI may result from specific characteristics of clean energy policies or technological developments that impact these indices differently from the price of Oil.

The Nasdaq Clean Edge Green Energy (CELS) index has a single cointegration with the Wilderhill (ECO) index, with a structural break on 16 July 2021. This evidence suggests that CELS maintains a long-term relationship exclusively with ECO, characterising it as a diversifying asset in relation to the other indices analysed. The date of the structural break may be associated with specific events that affected clean energy market conditions, highlighting the importance of understanding the historical context and political and economic changes during these periods.

The WTI index only shows cointegration with the Clean Energy Fuels (CLNE) index, with a structural break on 25 December 2020. This reinforces the idea that the WTI can act as a diversifying asset in relation to the other clean energy stock indices, which do not cointegrate with the WTI. The WTI's independence from the other clean energy indices suggests that the oil price behaviour is influenced by factors other than those affecting the sustainable energy stock markets, such as global oil supply and demand shocks and international energy policies.

5. DISCUSSION

Analysing the results reveals a scenario in which most clean energy indices show cointegration between them, indicating long-term relationships that reflect common trends in the clean energy sector. However, the relative independence of the WTI suggests that Oil still acts as an important and potentially diversifying external factor for investors focused on sustainable energy. Structural breaks in 2021 and 2022 in several indices point to significant events that have altered market dynamics, possibly including changes in environmental policies, technological innovations and the impacts of the COVID-19 pandemic.

In summary, the evidence of cointegration and structural breaks provides valuable information for constructing investment portfolios. Our understanding is to suggest that investors can consider the WTI to diversify portfolios dominated by clean energy assets, taking advantage of Oil's relative independence. On the other hand, the high correlation between clean energy indices suggests that, within this sector, diversification options are more limited, requiring careful analysis of the specific characteristics of each index and the macroeconomic forces that affect them.

6. CONCLUSION

The main purpose of this study was to analyse financial integration and test the hypothesis of diversifying assets between clean energy indices, specifically the Clean Energy Fuels (CLNE), Nasdaq Clean Edge Green Energy (CELS), S&P Global Clean Energy (SPGTCLEN), TISDALE Clean Energy (TCEC.CN), Wilderhill (ECO) and West Texas Intermediate (WTI) stock indices, over the period from 1 January 2018 to 23 November 2023.

This analysis provides a comprehensive insight into the long-term relationships between clean energy stock indices and the West Texas Intermediate (WTI) oil price index from 1 January 2018 to 23 November 2023. The cointegration observed between various clean energy indices indicates the existence of sustained relationships over time, reflecting shared trends in the sector. On the other hand, the relative independence of WTI from some of these indices suggests that Oil can play a diversifying role in investment portfolios focused on sustainable energy.

Regarding practical implications for investors and portfolio managers interested in clean energy, the results suggest the importance of considering not only the traditional indices of the sector but also the potential impact of the oil price on market dynamics. Including WTI in portfolios can mitigate risks associated with specific shocks in the clean energy sector, providing more robust diversification.

In addition, identifying structural breaks in different periods highlights the need for continuous monitoring of market conditions and the evolution of global energy policies. These events can significantly influence the relationships between the indices analysed, affecting asset allocation decisions.

This study has some important limitations, such as its reliance on specific historical data and its sensitivity to periods of economic or political instability. Future research could expand this study in several ways to advance the understanding of the relationships between clean energy indices and the WTI,: extending the study period to include more data and assessing the evolution of the relationships over time, especially in periods of significant changes in the global energy landscape; incorporating additional variables such as government policies, technological advances and climate change to understand cointegration patterns better; investigating and including other diversifying assets besides WTI, such as precious metals or commodities related to renewable energy; and using more complex multivariate models to capture dynamic interactions between multiple indices simultaneously. Addressing these areas may provide additional insights that benefit investors in building more robust and sustainable investment strategies in the context of the global energy transition.

REFERENCES

Annamalaisamy, B., Vepur Jayaraman, S. (2024), Do cryptocurrencies integrate with the indices of equity, sustainability, clean energy, and crude oil? A wavelet coherency approach. International Journal of Finance and Economics, 29(3), 2843.

Bondia, R., Ghosh, S., Kanjilal, K. (2016), International crude oil prices and the stock prices of clean energy and technology companies: Evidence from non-linear cointegration tests with unknown structural breaks. Energy, 101, e031.

Chambino, M., Dias, R., Horta, N. (2022), Time-varying Co-movements between WTI and European Capital Markets: Implications for Portfolio Diversification and Hedging Strategies. International Scientific-Business Conference - LIMEN 2022. Vol 8. Selected Papers No 31-49.

Dias, R., Alexandre, P., Teixeira, N., Chambino, M. (2023), Clean energy stocks: Resilient safe havens in the volatility of dirty cryptocurrencies. Energies, 16(13), 16135232.

Dias, R., Galvão, R., Alexandre, P. (2024), Precious metals as hedging assets: Evidence from MENA countries. Investment Management and Financial Innovations, 21(1), 157-167.

Dias, R., Heliodoro, P., Alexandre, P., Vasco, C. (2020), The Shocks between Oil Market to the Bric Stock Markets: A Generalised VAR Approach. 4th Internacional Scientific-Conference on Economics and Management - EMAN 2020.

Dias, R., Horta, N., Chambino, M. (2023), Clean energy action index efficiency: An analysis in global uncertainty contexts. Energies, 16(9), 3937.

Dias, R., Irfan, M., Galvão, R., Morão, A. (2024), Do sustainable energy stock indices and precious metals perform as hedging assets during periods of uncertainty in international markets?. In: Irfan, M., Hussainey, K., Bukhari, S., Nam, Y., editors. Issues of Sustainability in AI and New-Age Thematic Investing. United States: IGI Global. p104-123.

Dias, R., Santos, H., Heliodoro, P., Vasco, C., Alexandre, P. (2021), WTI Oil Shocks in Eastern European Stock Markets: A Var Approach. In: 5th EMAN Conference Proceedings (Part of EMAN Conference Collection), 71-84.

Dias, R., Teixeira, N., Alexandre, P., Chambino, M. (2023), Exploring the connection between clean and dirty energy: Implications for the transition to a carbon-resilient economy. Energies, 16(13), 4982.

Dong, X., Huang, L. (2024), Exploring ripple effect of oil price, fintech, and financial stress on clean energy stocks: A global perspective. Resources Policy, 89, 104582.

Dutta, A. (2017), Oil price uncertainty and clean energy stock returns: New evidence from crude oil volatility index. Journal of Cleaner Production, 164, 1157-1166.

Elgayar, A., Serag, S., Metawa, N. (2024), Navigating financial performance of the MENA region energy sector: The interplay of working capital and leverage. International Journal of Economics and Financial Issues, 14(2), 45-53.

Ferrer, R., Shahzad, S.J.H., López, R., Jareño, F. (2018), Time and frequency dynamics of connectedness between renewable energy stocks and crude oil prices. Energy Economics, 76, e022.

Gregory, A.W., Hansen, B.E. (1996a), Residual-based tests for cointegration in models with regime shifts. Journal of Econometrics, 70(1), 99-126.

Gregory, A.W., Hansen, B.E. (1996b), Tests for cointegration in models with regime and trend shifts. Oxford Bulletin of Economics and Statistics, 58(2), 555-560.

Jarque, C.M., Bera, A.K. (1980), Efficient tests for normality, homoscedasticity and serial independence of regression residuals. Economics Letters, 6(3), 255-259.

Levin, A., Lin, C.F., Chu, C.S.J. (2002), Unit root tests in panel data: Asymptotic and finite-sample properties. Journal of Econometrics, 108, 1-24.

Ren, B., Lucey, B. (2022), A clean, green haven?-Examining the relationship between clean energy, clean and dirty cryptocurrencies. Energy Economics, 109, 105951.

Santana, T., Horta, N., Revez, C., Santos Dias, R.M.T., Zebende, G.F. (2023), Effects of interdependence and contagion between oil and metals by ρ DCCA: An case of study about the COVID-19. Sustainability, 15(5), 3945.

Tedeschi, M., Foglia, M., Bouri, E., Dai, P.F. (2024), How does climate policy uncertainty affect financial markets? Evidence from Europe. Economics Letters, 234, 111443.

Teixeira, N., Dias, R.T., Pardal, P., Horta, N.R. (2023), Financial integration and comovements between capital markets and oil markets: An approach during the russian invasion of Ukraine in 2022. In: Lisboa, I., Teixeira, N., Segura, L., Krulický, T., Machová, V., editors. Handbook of Research on Acceleration Programs for SMEs. United States: IGI Global. p240-261.

Wang, Y., Cai, J. (2018), Structural break, stock prices of clean energy firms and carbon market. IOP Conference Series: Earth and Environmental Science, 120(1), e012018.