Qualitative Research Review Letter
https://qrrl.net/index.php/Journal/about
Online ISSN: 3007-0082
Print ISSN: 3007-0074
Vol. 3 No. 1 (2025)

RELATIONSHIP BETWEEN ENVIRONMENT-FRIENDLY EQUITIES. EVIDENCE FROM THE NASDAQ OMX GREEN ECONOMIC SECTORAL INDICES

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Abstract

The green equity market is experiencing rapid growth, presenting investment opportunities for market participants. This market includes equities from different sectors of the green economy. Understanding the relationships among green equities is essential for effective portfolio diversification and risk management. Hence, due to the limited existing literature on this subject, this study aims to examine the connections among green sector equities by analyzing the daily data of NASDAQ OMX green economic sector indices from 2010 to 2023. In the pre-COVID-19 sample, the correlation analysis indicated a strong interrelationship among energy efficiency, water, green building, and recycling sectors, which also exhibited close connections with nearly all other industries, except bio/clean fuels. On the other hand, the sectors of advanced materials, healthy living, bio/clean fuels, lighting, and natural resources exhibit a moderate degree of correlation among themselves. Following the outbreak of COVID-19, the connections between green equities have become more pronounced. However, the green transportation sector shows a moderate link to other green industries, particularly reflecting a weak correlation with the natural resources and pollution mitigation sectors. Therefore, sectors exhibiting weak to moderate connections can be regarded as viable options for a diversified portfolio. Furthermore, cointegration analysis reveals that there is no long-term equilibrium relationship among the green sectors, indicating that long-term investors with an environmental focus can benefit from favorable diversification opportunities. This research provides several important insights for both investors and policymakers.

Keywords: Green equity market, Green economic sectors, Correlation, Cointegration, Diversification opportunities, COVID-19.

Introduction

The quest for an optimal investment portfolio has posed significant challenges since the inception of stock markets. In response to this issue, Harry Markowitz (1952) advocated for the construction of portfolios comprising assets that demonstrate low correlation with one another, thereby facilitating diversification benefits. He further advised investors to spread their investments across multiple industries or sectors instead of focusing on a single industry, as companies within different sectors typically exhibit low correlation (Ahmad, et al., 2024; Leković, 2018). Consequently, investors, portfolio managers, and policymakers seek to understand the relationships among financial assets to enhance portfolio diversification and manage risk effectively (Saba, Fatima, Farooq, & Zafar, 2021; Saba, Tabish, & Khan, 2017).

Recently, there has been a significant increase in the attention of investors and policymakers towards green investments due to growing awareness of climate change and environmental problems (Chatziantoniou et al., 2022). Investors feel satisfaction by investing in all types of investments that will benefit the next generation (Chițimiea et al., 2021). Thus, by the end of the first quarter of 2024, global investments in green economic initiatives had surged to US$7.2 trillion, in stark contrast to the figure of less than US$1.5 trillion recorded in 2009 (Dai et al., 2024). The relationship or linkages among financial assets help investors and portfolio managers in efficient asset allocation, portfolio diversification and risk management (Chan et al., 2011; Mensi et al., 2024).

Therefore, extensive research has been conducted to investigate the relationships among green assets as well as between sustainable and conventional securities. For example, Abakah et al. (2023), Bondia et al. (2016), Fareed et al. (2022), Fernandes et al. (2023), Ferrer et al. (2021), Kanamura (2020), Lee et al. (2021), Nguyen et al. (2021), Reboredo (2018), Rizvi et al. (2022), Sharif et al. (2023), Syed et al. (2022), Tang et al. (2023), Tiwari et al. (2024). However, it is essential to prioritize green investments in key economic sectors, including agriculture, energy, fisheries, construction, forestry, tourism, industry, waste management, water resources and transportation, to facilitate the transition of the global economy to green and more sustainable (UNEP, 2011). Furthermore, the equities of these green companies offer more diversification opportunities to investors who prioritize environmental sustainability, than investment across conventional sectors (Boulatoff & Boyer, 2009). Additionally, the green equity market has experienced substantial growth, particularly in the aftermath of the COVID-19 pandemic (Sharma et al., 2022), as illustrated in Figure 1. Thus, it is crucial to investigate the connections between the green sectoral equities, as this area remains underexplored in the existing literature.

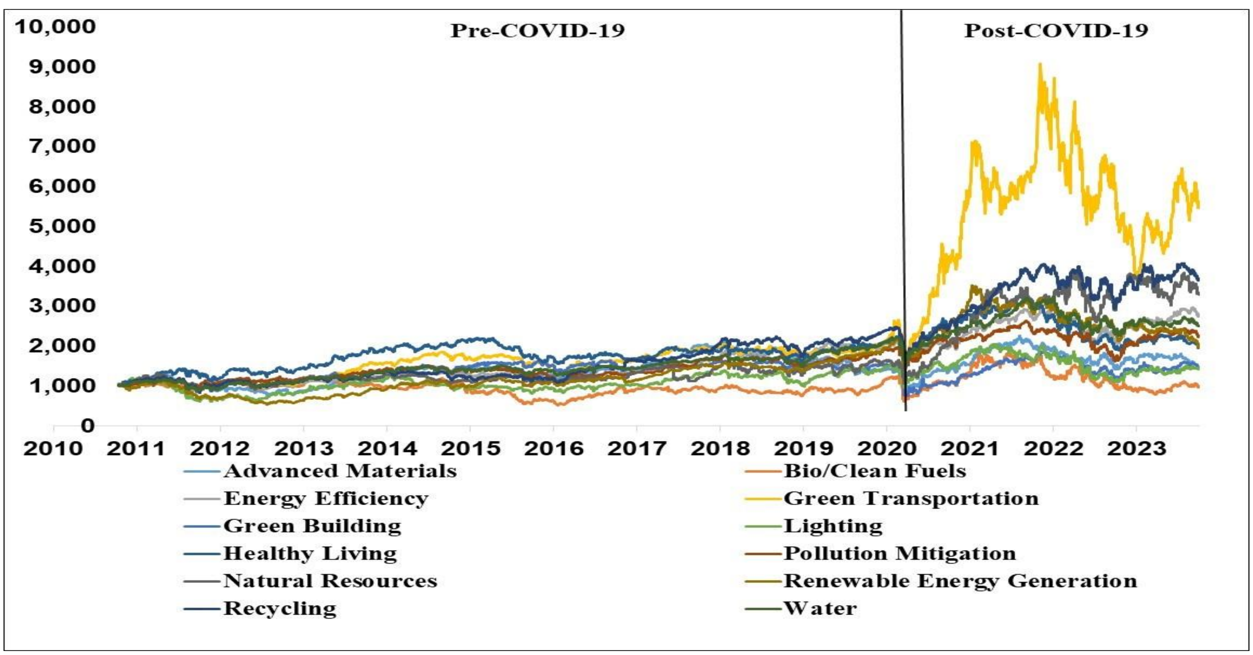

Figure 1: Plot of daily closing prices of green economic sectors

Therefore, the current investigation seeks to bridge this gap and enrich the body of knowledge in this significant domain by analyzing the relationship among equities of the green economic sectors. This study further explores the long-term connections between sectors, recognizing that investors who prioritize environmental considerations often commit to investments over extended periods. In addition, the COVID-19 pandemic has not only intensified financial and economic uncertainty but has also posted significant challenges in the areas of asset selection and risk management (Bouri et al., 2021; Shahzad et al., 2021). For this true reason, these inter-sectoral relationship is explored before and after the COVID-19 outbreak to comprehend the shifts in associations among green equities.

This research offers several significant contributions to the growing body of literature on green finance. First, this study highlights the pairwise connections among environment-friendly equities to guide investors in the area of portfolio diversification and risk management. These outcomes assist investors to make a diversified portfolio which reduces investment risk without affecting return significantly. Secondly, the interactions and connections formed throughout the COVID-19 period can significantly assist investors in their asset selection processes when confronted with analogous health crises in the future. Third, this research is grounded in the principles articulated by Markowitz (1952), who advocated for the inclusion of assets with minimal correlation to achieve optimal risk-adjusted returns. According to the Azhar, Iqbal and Imran (2025) constitutes a notable empirical contribution of the research. Fourth, cointegration analysis further aids investors to make strategic investment strategies over the long run. Fifth, the findings facilitate investors in making sound investment decisions across equities of sustainable companies (Saba, Fatima, Farooq, & Zafar, 2021; Saba, Tabish, & Khan, 2017). These investments direct financial resources to organizations that prioritize environmental protection while promoting economic advancement. Thus, this still contributes to meet the objectives laid down in environmental policies such as the United Nations Sustainable Development Goals, the Paris Agreement. Finally, policymakers have the opportunity to formulate development strategies by taking into account the interrelationships among green sectors, as the effects of policy can transition from one sector to another due to the presence of linkages.

The subsequent sections of this paper are structured as follows: Section 2 offers an extensive review of the existing literature, Section 3 outlines data and the econometric framework, Section 4 presents the empirical results and their discussion, while Section 5 concludes the study and discusses its policy implications.

Literature Review

Diversification among financial assets reduces investment risk without disturbing its return significantly (Surya & Natasha, 2018). At present, investors are adding more green assets in their investment (He & Cai, 2012) and the trend of green investment is increasing (Handayani & Rokhim, 2023). Therefore, a lot of research is conducted to explore the relationships among several assets as well as among green and conventional markets. These studies are summarized as under (Sarfraz, Raja, & Malik, 2022; Raja, Raju, & Raja, 2021; Sarfraz, Raju, & Aksar, 2018).

Starting from the work of Bondia et al. (2016), which examined the cointegration among oil prices, interest rates, and the stock performance of clean energy and technology companies, utilizing data spanning from 3 January 2003, to 5 June 2015. By applying a threshold cointegration methodology, the researchers identified a long-term relationship among the variables analyzed. Additionally, the causality results revealed that oil prices exert a short-term influence on clean energy stocks; however, this relationship does not persist over the long term.

In addition, Reboredo (2018) explored the co-movement among green bonds and other conventional financial markets by using daily index value from October 14, 2014 to August 31, 2017. Results of copula mode documented the strong correlation with treasury and corporate bond markets, while low co-movements are noticed for the energy commodity and stock market. It is found that investors in later markets offer diversification opportunities in green bonds (Sarfraz, Raja, & Malik, 2022; Raja, Raju, & Raja, 2021; Sarfraz, Raju, & Aksar, 2018)

Similarly, Kanamura (2020) investigated the correlation between green bonds and energy commodities. The daily indices values from 3 November, 2014 to 31 December, 2018 are analyzed by applying DCC and proposed correlation model. The findings of the study showed the positive correlation among MSCI and S&P green bonds and WTI and Brent crude oil. In contrast, the Solactive green bonds and conventional S&P bond indices exhibited a negative correlation with the oil market.

Moreover, Ferrer et al. (2021) investigated the interdependence between green and conventional markets through a wavelet-based network approach. The green markets are represented by green bonds and the stock market, while the traditional markets encompass bonds, stocks, oil, and gold. The empirical findings revealed significant connections between green bonds and the bond markets. Conversely, green stocks exhibited a strong correlation with the conventional stock market. Notably, the analysis indicated a lack of association between the green bond market and the green stock market, presenting valuable diversification opportunities for environmentally conscious investors who wish to maintain their commitment to sustainability (Firdos, Khan & Atta, 2024; Fatima, Khan & Kousar, 2024; Farooq at al., 2021).

Similarly, utilizing quantile Granger causality analysis, Lee et al. (2021) investigated the causal relationships among green bonds, geopolitical risk, and oil prices, employing data from the United States spanning 2013 to 2019. Their findings revealed bi-directional relationships between green bonds and oil prices in the lower quantiles (ul Haq, 2019; 2017). Another important contribution is made by Nguyen et al. (2021) by exploring the relationship among green bonds and other markets including conventional bonds, stocks, clean energy and commodities. The daily values spanning from 2008 to 2019 were examined utilizing wavelet correlation methodology (Firdos, Khan & Atta, 2024; Fatima, Khan & Kousar, 2024; Farooq at al., 2021). The analysis indicated that green bonds exhibit a low correlation with commodities and the stock market, highlighting their potential for diversification. In contrast, the correlation among stocks, clean energy, and commodities is noticed to be relatively high. Additionally, Fareed et al. (2022) examined the associations between COVID-19, cryptocurrency, green stocks, crude oil and carbon markets by utilizing the rolling window multiple correlation approach (Saba, Fatima, Farooq, & Zafar, 2021). The analysis utilized daily data collected from January 22, 2020, to December 20, 2021. The bivariate investigation indicated a positive correlation between COVID-19 and the carbon efficiency index, while a negative relationship was observed in the oil market. Additionally, a significant non-linear association was identified between COVID-19 and the cryptocurrency market. In contrast, the multivariate analysis revealed a positive correlation across all markets (Akhtar, et al., 2021).

Moreover, Syed et al. (2022) examined the asymmetric interactions among green bonds, oil prices, clean energy, Bitcoin, and economic policy uncertainty (EPU) utilizing the Non-linear Autoregressive Distributed Lag (NARDL) methodology. Analyzing daily data from 2016 to 2021, the findings confirmed the presence of asymmetric cointegration among the variables. The NARDL analysis revealed that negative shocks in EPU enhance the performance of green bonds, whereas positive shocks in EPU adversely affect them. Additionally, a bidirectional causality was observed between Bitcoin and green bonds (ul Haq, 2019; 2017). The analysis revealed a direct relationship in the movements of green bonds, oil prices, and stocks in the clean energy sector. In addition, by utilizing the Johansen cointegration test, Rizvi et al. (2022) found no evidence of cointegration among green energy, gray energy, equity, and bond markets. This conclusion was drawn from an analysis of daily ETF data spanning from 2015 to 2020 in the United States.

Furthermore, the correlation between blockchain and environment-friendly assets such as S&P green bonds index and MSCI global environment index was investigated by Abakah et al. (2023). Using rolling window correlation approach, low correlation was noticed among blockchain and green assets before the emergence of COVID-19 pandemic, while this association became high during the health crisis and Russia-Ukraine conflict. In the same pattern, Fernandes et al. (2023) analyzed the correlation between green bonds, sectoral stocks and bonds indices from by using daily data from 28 November, 2008 to 16 August, 2022. The results of Multifractal Detrended Cross-Correlations methodology indicated that bond indices related to consumer staples, along with equity indices pertaining to the information technology and real estate sectors, can serve as effective hedging instruments for investments in green bonds (ul Haq, 2019; 2017).

In addition, Sharif et al. (2023) examined the correlation across green economic indices, green and black cryptocurrencies in the United States, European and Asian markets. Quantile spillover approach was used to analyze the daily data from 9 November, 2017 to 4 April, 2022. The results disclosed the strong connections between green economic and clean cryptocurrency markets, than linkages with dirty cryptocurrencies. Overall, it was documented that spillover among markets was high in all regions, particularly in Asia (Azhar, 2024). Similarly, Tang et al. (2023) investigated the dynamic correlation between green bonds, fossil fuel and clean energy market with the help of Bayesian DCC-MGARCH model. The results demonstrated that green bonds have a weak negative correlation with clean energy and fossil fuel markets such as gasoline, heating oil, natural gas, Brent and WTI oil. These associations suggested that green bonds can be used as a hedging instrument against clean energy and fossil fuel. It has been noted that there exists a more pronounced correlation between green bonds, clean energy, and WTI oil compared to Brent oil. Consequently, stakeholders should prioritize the price fluctuations of WTI oil over those of Brent when considering investments in green bonds.

Finally, Tiwari et al. (2024) explored the integration among green bonds and several other sustainable assets using wavelet correlation and multiscale quantile correlation methodologies. The daily data from 31 August, 2010 to 13 January 2022 was used for analysis. The findings of this study indicated that green bond indices present avenues for diversification across different quantiles and temporal dimensions when combined with green equities. The results further demonstrated that investors can leverage safe-haven and the hedging characteristics of green bonds in relation to green stocks during periods of market volatility.

The existing literature indicates that scholars have predominantly investigated the relationship between green or sustainable markets, and across eco-friendly markets and traditional markets mostly at an aggregate level. However, the growth of green investment is becoming increasingly prominent, involving equities from a range of eco-friendly companies that are active in several sectors, such as green transportation, renewable energy, waste management, recycling, water management, and material efficiency (Azhar, 2024; Arif et al., 2021). These industries not only offer enhanced opportunities for diversification but also possess considerable growth potential (Boulatoff & Boyer, 2009). So, equities of these companies present a compelling opportunity for sustainable investors, as they consistently seek out expanding markets that offer the potential for higher returns (Jayasuriya, 2008). Therefore, this study aims to address the existing research gap by elucidating the interrelationships among the equities within green economic sectors. The findings are intended to assist investors and policymakers in the development of optimal portfolios and the enhanced management of the green equity market.

Data and Research Methodology

Data

The objective of the study is to explore the relationships among the equities of green sectors. To achieve this end, the daily closing values of the NASDAQ OMX green economic sectoral indices are utilized, covering the period from 15 October, 2010, to 30 September, 2023. The reason behind the selection of these indices is the easy data availability and global recognition. These indices include energy efficiency, advanced materials, green transportation, bio/clean fuels, lighting, healthy living, green building, pollution mitigation, recycling, natural resources, water and renewable energy generation. Data is collected from the website of investing.com.

Furthermore, to examine the effects of COVID-19 on sectoral interdependence, this research is organized into two distinct sub-sample periods: the pre-COVID-19 phase, spanning from October 15, 2010, to March 10, 2020, and the post-COVID-19 phase, which extends from March 11, 2020, to September 30, 2023. This specific cutoff date is determined in relation to the World Health Organization's announcement on March 11, 2020, which classified COVID-19 as a global pandemic (WHO, 2020).

The daily closing values are converted into return by calculating the first difference of their logarithmic values.

$$R_{i,t} = \left(\ln p_{i,t} - \ln p_{i,t-1}\right) \times 100 \quad (1)$$

Pearson Correlation Coefficient

This study applied the Pearson correlation approach to explore the interconnections among green sector equities. The correlation coefficients, which can vary from -1 to +1, quantify both the strength and direction of relationships between variables. A coefficient of -1 indicates a perfect negative correlation, whereas a coefficient of +1 signifies a perfect positive correlation. A coefficient value of 0 denotes the absence of correlation among the variables. Grasping and interpreting the correlation coefficient is relatively easy. The calculation of Pearson correlation coefficients is conducted in the following manner.

$$r = \frac{\sum(X_i - \overline{X})(Y_i - \overline{Y})}{n\sigma_X.\sigma_Y} \quad (2)$$

In this context, X_i and Y_i represent the returns of sectors X and Y, respectively. The symbols $\overline{X}$ and $\overline{Y}$ denote the mean returns for sectors X and Y. Additionally, σX and σY indicate the standard deviations of sectors X and Y, while n signifies the total number of observations.

However, correlation analysis evaluates the extent to which two-time series move together over a specified duration, but it does not adequately establish the existence of a long-term stationary relationship between them. To ascertain whether an equilibrium relationship is present, it is necessary to conduct a cointegration analysis. For this purpose, regression among two variables can be expressed as, $Y_t = \beta_1 + \beta_2 X_t + \mu_t$. According to the assumption of ordinary least squares.

$$\beta_2 = \frac{\sum(X_t - \overline{X})(Y_t - \overline{Y})}{(X_t - \overline{X})^2} \quad (3)$$

For example, $X_t \sim I\,(1)$, while $Y_t \sim I\,(0)$. Here, X_t is assumed non-stationary whereas Y_t is a stationary series at level. Despite the presence of a correlation between both series, it is not necessary to have a long-term relationship between these two variables. As Xt is characterized by non-stationarity, its variance will progressively increase, which results in the estimator $\beta 2$ approaching 0 with an increasing sample size. Due to the absence of a nonlimiting or asymptotic distribution, the estimator $\beta 2$ is consequently no longer considered unbiased.

Unit Root Test

In order to analyze the cointegration among green sectors, it is imperative to first ascertain that each series is integrated of the same order (Engle & Granger, 1987). The Augmented Dickey-Fuller (ADF) test is widely recognized as the predominant technique for assessing the presence of a unit root within a time series (Nalin & Güler, 2015). This test takes place in the following form.

$$\Delta Y_t = \delta Y_{t-1} + \mu_t \qquad (4)$$

In this context, Y_t denotes the sector index for a specific day, while Y_{t-1} indicates the sector index from the preceding day. The symbol δ and u_t refer to the coefficient and the error term respectively. Afterwards, optimal lag is selected for cointegration test using Akaike Information Criterion (AIC), Schwarz Information Criteria (SIC).

Johansen Cointegration Test

The Johansen test is employed to find the long run relationship among green economic sectors. When two or more sectors display a tendency to move in tandem, they are regarded as being integrated. The cointegration relationship among green industries can be identified using trace value or Eigenvalue by using the following equation.

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{g} ln(1 - \hat{\lambda} i) \qquad (5)$$

$$\lambda_{max} = -T\, ln(1 - \hat{\lambda} i + 1) \qquad (6)$$

Empirical Results and Discussion

Descriptive Statistics

The descriptive statistics of green sector's returns are presented in Table 1 and 2, which refer to the pre, and post-COVID-19 sample respectively. Table 1 shows the daily mean returns that are positive for all green sectoral equities, except bio/clean fuels. This represents a positive and promising indication within the realm of green and environment-friendly investment. However, it is observed that the green transportation sector stands out among green sectors, showcasing the highest daily mean return, as reported by Chen et al. (2023). Conversely, the bio/clean fuels sector is found at the opposite end, reflecting a negative return, as noticed by Demiralay et al. (2023). This sector not only yields the lowest returns but also exhibits the significantly high risk as indicated by their standard deviation, which may be attributed to elevated production costs (FASTECH, 2022). Alternatively, the water sector, with its lowest standard deviation, represents an industry that is associated with the least amount of risk.

Furthermore, according to the descriptive statistics illustrated in Table 3, there has been a substantial increase in the daily returns of all green sectors in the aftermath of the COVID-19 pandemic, except healthy living and renewable energy sectors. Although, bio/clean fuels experienced enhanced returns as a result of heightened demand during the COVID-19 pandemic (Zhang et al., 2024), their associated risks escalated considerably in the post-pandemic period. Notably, all industries showed an increase in standard deviation, but this rise was less pronounced than the corresponding growth rate of returns. On the other hand, the results of kurtosis and skewness of all return series display a leptokurtic and a left-skewed distribution marked by a heavy tail and a distinct peak.

Table 1. Descriptive Statistics of Returns in Green Sectors in the Pre-COVID-19 sample (October 15, 2010 - March 10, 2020)

Sector	Min.	Max.	Mean	SD	Skewness	Kurtosis
Advanced Materials	-9.041	8.166	0.0046	1.38	-0.39	5.02
Bio/Clean Fuels	-16.627	11.251	-0.0048	1.50	-0.77	9.67
Energy Efficiency	-7.908	6.310	0.0213	1.17	-0.49	4.72
Green Transportation	-10.740	5.756	0.0304	1.04	-0.73	7.77

Green Building	-8.938	5.528	0.0086	1.02	-0.83	7.99
Lighting	-7.029	6.829	0.0049	1.39	-0.43	2.83
Healthy Living	-7.785	7.493	0.0229	1.09	-0.48	6.67
Pollution Mitigation	-6.431	4.965	0.0200	1.04	-0.31	2.96
Natural Resources	-31.895	7.238	0.0143	1.50	-4.25	86.50
Renewable Energy Generation	-7.152	5.242	0.0267	1.00	-0.60	4.17
Recycling	-7.739	5.368	0.0301	1.05	-0.43	4.48
Water	-6.189	4.182	0.0274	0.90	-0.54	4.29

Table 2. Descriptive Statistics of Returns in Green Sectors in the Post-COVID-19 sample (March 11, 2020 - September 30, 2023)

Sector	Min.	Max.	Mean	SD	Skewness	Kurtosis
Advanced Materials	-12.100	7.698	0.0282	1.69	-0.54	6.07
Bio/Clean Fuels	-18.196	13.393	0.0063	2.52	-0.73	7.17
Energy Efficiency	-12.155	10.179	0.0529	1.52	-0.23	9.54
Green Transportation	-13.651	11.448	0.1054	2.74	-0.27	2.14
Green Building	-17.084	8.604	0.0166	1.89	-1.40	15.92
Lighting	-11.199	10.826	0.0222	1.95	-0.02	3.59
Healthy Living	-11.116	10.443	0.0116	1.49	-0.24	9.70
Pollution Mitigation	-12.744	6.941	0.0328	1.46	-0.66	8.96
Natural Resources	-	12.443	0.0890	2.05	-0.56	7.83

	13.400					
Renewable Energy Generation	-15.258	8.931	0.0016	1.54	-0.90	13.37
Recycling	-11.904	8.457	0.0601	1.56	-0.75	7.71
Water	-10.335	8.759	0.0266	1.32	-0.46	10.31

Correlation Results

The findings regarding correlations for the pre-COVID-19 and post-COVID-19 samples, are detailed in Tables 3 and 4. The results in both sample reveal a positive correlation across all sector pairs, indicating that green sectors exhibit uniform directional movements. Table 3 documents that energy efficiency, water, green building and recycling industries show not only strong correlations with each other but are closely linked with nearly all other sectors, except for bio/clean fuels, which limits their potential for diversification.

In contrast, the bio/clean fuels sector shows a moderate relationship with all other green economic sectors, especially a weak association with lighting and natural resources, suggesting that it can be combined with any green sectors within a portfolio. It has been noted that the sectors of advanced materials, healthy living, bio/clean fuels, lighting and natural resources show a moderate correlation with one another. Furthermore, green transportation, pollution mitigation, and renewable energy generation have a strong connection with the majority of other sectors. The heterogeneous interactions among green sectors are instrumental in establishing a well-diversified portfolio and in conducting effective risk management activities (Pham, 2021).

Moreover, Table 4 shows a notable increase in the correlation among sectors during the post-COVID-19 period, when contrasted with the pre-

COVID-19 results. This trend is consistent with the findings of Elsayed et al. (2022) and Umar et al. (2022), who observed that asset connections typically intensify during periods of crisis. Despite the increase in linkages after COVID-19 outbreak, the green transportation sector shows a moderate relationship with other green industries, particularly demonstrating a weak correlation with the natural resources and pollution mitigation. Similarly, the bio/clean fuels and natural resources sectors present a promising investment avenue in post-pandemic, as they maintain a moderate correlation with most other sectors. Therefore, pairs of green sectors that represent weak to moderate correlations may provide significant diversification opportunities for environment-friendly investors.

Table 3. Correlation among Green Economic Sectors in the Pre-COVID-19 period (October 15, 2010 - March 10, 2020)

Sector	AM	BIO	ENEF	GT	GB	LGT	HL	PM	NR	REG	REC	WTR
Advanced Materials (AM)	1											
Bio/Clean Fuels (BIO)	0.436	1										
Energy Efficiency (ENEF)	0.722	0.508	1									
Green Transportation (GT)	0.630	0.519	0.777	1								
Green Building (GB)	0.644	0.477	0.791	0.721	1							
Lighting (LGT)	0.586	0.394	0.737	0.633	0.668	1						
Healthy Living	0.495	0.413	0.621	0.587	0.621	0.536	1					

(HL)												
Pollution Mitigation (PM)	0.644	0.445	0.773	0.674	0.727	0.699	0.556	1				
Natural Resources (NR)	0.510	0.360	0.651	0.558	0.569	0.510	0.438	0.554	1			
Renewable Energy Generation (REG)	0.585	0.458	0.717	0.680	0.715	0.649	0.551	0.687	0.490	1		
Recycling (REC)	0.663	0.502	0.836	0.752	0.803	0.674	0.600	0.716	0.621	0.694	1	
Water (WTR)	0.676	0.520	0.858	0.777	0.839	0.728	0.634	0.800	0.631	0.770	0.841	1

Table 4. Correlation among Green Economic Sectors in the Post-COVID-19 period (March 11, 2020 - September 30, 2023)

Sector	AM	BIO	ENEF	GT	GB	LGT	HL	PM	NR	REG	REC	WTR
Advanced Materials (AM)	1											
Bio/Clean Fuels (BIO)	0.536	1										
Energy Efficiency (ENEF)	0.790	0.590	1									
Green Transportation (GT)	0.466	0.470	0.544	1								
Green Building (GB)	0.738	0.616	0.778	0.471	1							
Lighting (LGT)	0.674	0.542	0.761	0.579	0.623	1						
Healthy Living (HL)	0.592	0.573	0.675	0.505	0.638	0.624	1					

Pollution Mitigation (PM)	0.635	0.454	0.671	0.353	0.617	0.578	0.604	1				
Natural Resources (NR)	0.632	0.513	0.650	0.391	0.647	0.531	0.488	0.456	1			
Renewable Energy Generation (REG)	0.688	0.624	0.765	0.568	0.662	0.717	0.655	0.637	0.544	1		
Recycling (REC)	0.764	0.603	0.848	0.496	0.796	0.683	0.644	0.604	0.715	0.714	1	
Water (WTR)	0.733	0.553	0.864	0.505	0.748	0.682	0.664	0.660	0.604	0.776	0.843	1

Unit Root Test

To conduct the Johansen cointegration test, it is essential that all-time series must be integrated at the same order. Thus, we carry out the ADF unit root test to verify this requirement. As seen in Table 5, all sectoral time series are non-stationary at level, I (0) but achieve stationarity after taking the first difference, I (1), in both sub-sample periods. These findings validate the use of the cointegration test.

Table 5. ADF Test results

Sector	Pre-Covid-19				Post-Covid-19			
	At Level 0		At Level 1		At Level 0		At Level 1	
	t-stat	Prob.	t-stat	Prob.	t-stat	Prob.	t-stat	Prob.
Advanced Materials	-1.22	0.90	-13.51	0.01	-2.07	0.55	-9.72	0.01
Bio/Clean Fuels	-2.56	0.34	-12.51	0.01	-2.34	0.43	-9.88	0.01
Energy Efficiency	-2.74	0.26	-13.05	0.01	-2.51	0.36	-9.44	0.01
Green Transportation	-2.80	0.24	-12.35	0.01	-2.43	0.40	-8.87	0.01
Green Building	-1.59	0.75	-13.03	0.01	-1.89	0.63	-9.98	0.01
Lighting	-2.61	0.32	-13.34	0.01	-2.77	0.25	-10.00	0.01
Healthy Living	-2.18	0.50	-13.22	0.01	-3.31	0.07	-9.59	0.01
Pollution Mitigation	-2.68	0.29	-13.87	0.01	-2.66	0.30	-9.58	0.01
Natural Resources	-4.48	0.10	-13.38	0.01	-1.99	0.58	-9.75	0.01

Renewable Energy Generation	-2.28	0.46	-11.51	0.01	-2.58	0.33	-9.11	0.01
Recycling	-2.41	0.41	-12.77	0.01	-2.35	0.43	-9.59	0.01
Water	-2.85	0.22	-13.29	0.01	-2.61	0.32	-9.48	0.01

Optimal Lag Selection

It is crucial to establish the optimal VAR lag length to ensure reliable outcomes in Johansen cointegration analysis. The outcomes of the FPE (Final Prediction Error), AIC (Akaike Information Criterion), SC (Schwarz Information Criterion), and HQ (Hannan-Quinn Information Criterion) are displayed in Table 6. For the pre-COVID sample, both SC and HQ indicate that the optimal lag is 1, while FPE and AIC suggest a lag of 2. Consequently, lag 2 is deemed optimal for the cointegration test. In contrast, all selection criteria point to lag 1 for the post-COVID-19 sample, which is utilized for analysis during the post-pandemic period.

Table 6: Optimal VAR Lag Selection Criteria

Optimal Lag	**FPE**	**AIC**	**SC**	**HQ**
Pre-COVID-19				
0	5.41e+47	143.97	143.99	143.98
1	1.20e+24	89.50	89.88*	89.64*
2	1.15e+24*	89.46*	90.18	89.72
3	1.19e+24	89.49	90.56	89.88
4	1.22e+24	89.51	90.93	90.03
Post-COVID-19				
0	7.95e+51	153.56	153.62	153.58
1	3.25e+33*	111.22*	112.04*	111.53*
2	3.38e+33	111.26	112.83	111.86
3	3.83e+33	111.38	113.71	112.27

4	4.36e+33	111.51	114.60	112.69

* refers to the optimal lag order

Multivariate Cointegration Test

The findings from the Johansen cointegration test are presented in Table 7. Based on the trace statistics and maximum eigenvalue, the null hypothesis indicating no integration fails to be rejected at the 5% confidence level for both sub-samples. This indicates that there is no long-term relationship among green economic sectors before and after the COVID-19 outbreak. Consequently, sustainable investors can consider long-term investments in these sectors to achieve optimal returns while fulfilling environmental objectives.

Table 7. Results of Multivariate Cointegration Test

No. of CE(s)	Eigenvalue	Trace stat.	Critical Value at 5%	Max. Eigen	Critical Value at 5%
Pre-COVID-19					
0	0.025267	335.24	358.72	61.75	79.98
1	0.020691	273.48	306.89	50.45	73.94
2	0.017999	223.03	259.03	43.83	67.91
3	0.016040	179.20	215.12	39.02	61.81
4	0.014765	140.19	175.17	35.89	55.73
5	0.012311	104.29	139.28	29.89	49.59
Post-COVID-19					
0	0.067040	324.56	334.98	64.19	76.58
1	0.059738	260.37	285.14	56.98	70.54
2	0.051817	203.39	239.24	49.22	64.51
3	0.042475	154.18	197.37	40.15	58.43
4	0.026970	114.03	159.53	25.29	52.36
5	0.025136	88.74	125.62	23.55	46.23

Conclusion

The increasing concern regarding climate change and environmental challenges has led to a notable rise in interest from both investors and policymakers in green investments (Chatziantoniou et al., 2022). This heightened interest has resulted in substantial growth in the green equity market, particularly following the onset of the COVID-19 pandemic (Sharma et al., 2022). However, the green equity market encompasses equities from various sectors of the green economy. The knowledge about the heterogeneous interrelationships among green equities is essential for investors aiming to construct a diversified portfolio and manage risk effectively (Pham, 2021). Therefore, this study aims to explore the relationships among green sector equities to assist stakeholders in their decision-making processes. Additionally, the COVID-19 pandemic has altered investment behaviors and lifestyles, making it pertinent to examine these relationships both before and following the pandemic to identify potential investment opportunities for investors. To fulfill this objective, the research utilizes daily closing values of NASDAQ OMX green sectoral indices spanning from October 15, 2010, to September 30, 2023.

The pre-COVID-19 Pearson correlation analysis reveals that energy efficiency, water, green building and recycling industries demonstrate significant interconnections and are strongly associated with almost all other sectors, with the exception of bio/clean fuels, which restricts their ability to diversify. Conversely, the bio/clean fuels sector demonstrates a moderate correlation with other green economic sectors, particularly showing a weak link with lighting and natural resources, indicating its potential to be integrated with any green sectors in a portfolio. It is essential to emphasize that different sectors exhibit strong ties with certain industries while maintaining moderate levels of connection with others. For instance, it has been observed that advanced materials, healthy living, bio/clean fuels, lighting and natural resources exhibit a moderate level of correlation with each other but have significantly high correlation with other sectors.

Additionally, the results from the post-COVID-19 sample reveal a significant rise in the correlation between sectors following the pandemic when compared to the pre-COVID-19 data. However, various green sectors offer promising diversification opportunities. For example, the green transportation sector exhibits a moderate link to other green industries, specifically showing a weak correlation with both the natural resources and pollution mitigation sectors. Likewise, the bio/clean fuels and natural resources sectors offer a favorable investment opportunity in the post-pandemic landscape, as they sustain a moderate correlation with the majority of other sectors.

Furthermore, the Johansen cointegration test results indicates that there is no long run relationship among green economic sector in both pre and post-COVID-19 samples. These findings show that environment-friendly investors can earn best risk-adjusted returns in long run by making a diversified portfolio across equities of green sectors.

This research provides several practical insights for environmentally-conscious investors and policymakers. First, sectors with weak to moderate connections aid investors and portfolio managers in building a diversified portfolio, allowing them to achieve optimal risk-adjusted returns. For instance, advanced material, healthy living, the bio/clean fuels, lighting and natural resources industries exhibit moderate level connections with each other, offering significant diversification opportunities in pre-COVID-19 period. Second, the inter-sector relationships that emerged following the health crisis assist investors in adjusting their portfolios during such type of emergencies. For example, green transportation has a weak correlation with the natural resources and pollution mitigation sectors, making it a viable option for portfolio construction. Third, cointegration analysis suggests that long-term diversification options are available for green investors because there is no established cointegration relationship among green economic sectors. Finally, policymakers can craft development strategies by analyzing the linkages among sectors, as the impact of policies can shift across sectors due to these relationships. For example, any development initiatives in green building sectors can have beneficial effects on various other sectors, owing to the interconnectedness that exists among them.

This research presents several limitations that pave the way for future investigations. First, the study exclusively focuses on the NASDAQ OMX green sector indices to represent green investment. Nonetheless, there exists a variety of eco-friendly financial instruments offered by financial markets, such as the MSCI ESG indices, which could be considered for investment purposes. Thus, an examination of the connections between these assets could be done in future studies to offer insights to market participants. Second, investigating the relationships among various asset classes, including green equities, green bonds, and other sustainable investments, could lead to provide more diversification opportunities and optimal returns. Thus, further research could be conducted to broaden the current study's scope. Third, this research employed the Pearson correlation and Johansen cointegration methods to analyze the connections among green equities. However, the relationships between financial assets fluctuates due to changes in market conditions. Therefore, it is essential to utilize advanced connectedness techniques such as the TVP-VAR framework to assess the time-varying relationships among green sectors.

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