Exploring the Green Bonds and Stock Markets' Dependence Structures

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ABSTRACT

Using the copula method, this study explores the dependence structure that exists between the Clean Energy Market and the Stock Markets of industrialized countries. To determine the degree of dependence between the stock markets of the developed countries included in this study and the market for clean energy, this study was established. The results of the study indicate a relationship between stock markets and the market for clean energy supplies. According to the findings of this study, investors, policymakers, and financial analysts benefit from it in terms of investments, risk management, and future projections.

Keywords: Behavioral finance, Cognitive Illusions, Framing Effect, Heuristic Bias, Snakebite Bias, investment, Pakistan.

1. Introduction

Climate finance is currently one of the most important areas in the world. Global events such as world climate summits under the United Nations Framework Convention on Climate have made this evident [1]. The concept of the clean energy market derives its value from the climate finance domain. However, a country's stock market is a powerful barometer for measuring economic growth.

Previous research shows that the commodity market has been one of a strong influence on stock returns. For instance, [2] found that the price elevation of crude oil slows economic growth and increases inflation expectations in the short term. They further state that an increase in oil prices has a detrimental impact on stock prices and economic activities. Oil is one of the primary sources of energy. Therefore, an analogy can be created to highlight the impact of the energy market on stock returns. However, empirical evidence of this is necessary. This study fills this gap.

Moreover, a paradigm shift from traditional markets to clean markets is evident. For instance, a study conducted by [3] found a connection between the energy and stock markets. Clean energy includes renewable and sustainable sources for generating electricity, rather than using expensive fossil fuels, which also affects the environment. For some researchers, the energy market can be considered a safe haven. However, there is a dearth of literature on this topic. Therefore, the underlying study aims to test the dependence structure, as the direction and correlation among markets determine the course of direction for portfolio investors.

It is generally agreed that climate finance is a major issue in modern times. Global events, such as the holding of global climate conferences under the aegis of the United Nations Framework Convention on Climate [4], have proven the certainty of the situation. The concept of a clean energy market is meaningful in the field of climate finance. On the contrary, the stock market is a reliable indicator of economic expansion within a country.

According to previous studies, commodity markets significantly impact stock returns. According to research [5], rising expectations of future inflation and slower economic growth are the result of rising short-term crude oil prices. This also suggests that rising oil prices have a negative effect on the economy and stock markets. Oil is widely acknowledged to be a significant energy resource. Thus, a parallel can be drawn to emphasize the significance of the energy market in stock returns. However, there is great value in including empirical data. This study fills this knowledge gap.

Furthermore, it is obvious that a global change is underway, with clean markets gradually replacing old ones. An association between the stock market and energy was discovered in [6]. To produce power, clean energy projects look to renewable and non-depleting resources rather than to more expensive and environmentally damaging fossil fuels. Some academics argue that the energy market is a safe and steady place to invest money. However, it should be mentioned that academic studies in this area are lacking. Thus, this study seeks to assess the interdependence structure in terms of how market direction and correlation impact investors' portfolio decision-making.

2. Literature Review

Academic interest in the subject of energy markets has increased since a paradigm shift has been made by developed countries towards green and ethical finance. Unlike the crypto market, which is volatile and has become common all over the world due to its digital nature, the energy market has not yet been penetrated by investors from developing countries. Only developed countries have started transitioning in the first place [7].

In this connection, it can offer portfolio benefits for investors through diversification in this market. It can be argued that investment in securities in the clean energy sector is less risky for investors intending to create portfolios. According to Kahagalle and Jones (2021), green investments such as green bonds are green because they invest in renewable energy. Therefore, investment in such a market offers investors an optimal portfolio. Therefore, [8]examined the correlation between oil prices and alternative clean energy stocks and claimed that technology stock prices have a greater impact on US clean energy stock prices than oil prices using the Granger causality test and LA-VAR model. Kumar, Managi [9], confirmed similar results.

Furthermore, [3] examined the long-run link between the stock prices of clean energy companies, oil prices, technology stocks, and interest rates, using the structural break cointegration method. They discovered substantial short-term causal correlations between the renewable energy stock prices and macroeconomic variables. Lundgren et al. (2018) discovered a network of links between renewable energy stocks, financial market uncertainty, and politics. While, [10] highlighted the importance of creating clean energy, such as solar and wind energy, by establishing clean energy legislation in light of the current energy crisis and the consistently fluctuating price of oil. Moreover, [11] employed a dynamic time-frequency analysis method to investigate the interconnection of renewable energy sources. Additionally, [12] emphasized the risk profile of clean energy equities. Unexpectedly, research on the volatility of clean energy equities and their relationship with other markets is still lacking. The underlying study attempts to further this area of research.

The academic community has shown an increased interest in the topic of energy markets following a paradigm shift towards green and ethical finance in developed countries. Investors hailing from emerging nations have not substantially influenced the energy sector. This is in stark contrast to the cryptocurrency market, which is characterized by its high volatility and widespread adoption resulting from its intrinsic digital properties. Currently, only the most advanced nations have initiated the transition process [13, 14].

In the current situation, it is plausible that the market under consideration may offer investors a portfolio advantage through diversification. There is an argument to be made that investing in clean energy securities may present a comparatively lower risk for investors seeking to construct a portfolio, as opposed to alternative investment options [12]. Ren, Hao [15] assert that green investments, exemplified by green bonds, are seen as environmentally sustainable due to their allocation of funds towards renewable energy sources. Therefore, the act of investing in such a market offers investors the most optimal portfolio. Henriques and Sadorsky [16] did a study examined the correlation between the price of oil and valuation of alternative clean energy firms. The researchers employed the Granger causality test and the LA-VAR model to substantiate their claim that the valuation of US renewable energy firms is more significantly impacted by the price of technology stocks than by oil prices. The study conducted by Kumar and Managi [9] demonstrated equivalent results.

Moreover, [17] employed structural break cointegration methodology to examine the enduring relationship between the stock prices of renewable energy enterprises, oil prices, technology stocks, and interest rates. There was a lack of statistically significant links among the variables. They discovered notable short-term causal connections between the stock values of renewable energy firms and other macroeconomic variables. By contrast, Lundgren [18] demonstrated the existence of a complex interplay between renewable energy stocks, financial market volatility, and political factors. Chien, Paramaiah [12] highlights the significance of promoting clean energy, specifically solar and wind energy, through the implementation of clean energy legislation, in response to the prevailing energy crisis and the volatile nature of oil prices. It is crucial to underscore the importance of developing clean energy sources considering the ongoing energy crisis and persistent fluctuations in oil prices. Furthermore, the study conducted by Ferreruela and Mallor [19] examined the interconnectedness of renewable energy providers using a dynamic time-frequency analysis approach. The purpose of this activity was to collect data for research investigation. Moreover, research conducted by Kocaarslan and Soytas [20] highlights the need to consider the risk profile associated with clean energy equities. Remarkably, research on the volatility of clean energy stocks and their interrelation with other financial markets is scarce. This study aims to contribute to the advancement of research in this academic domain.

3. Research Model

Examining the following indexes and periods reveals the clean energy sector's dependency on developed world stock markets. Data on the clean energy market were taken from Standard & Poor's worldwide clean energy indices, while stock market indices were obtained from investing.com. The data were loaded into an application for analysis after sorting in Excel. The following formula was used to compute the returns:

To examine the level of similarity between the stock markets of developing and industrialized nations, it is imperative to utilize various indices and time intervals. The data pertaining to stock market indices and statistics of the clean energy market were obtained from reputable sources. The stock market index data were obtained from investing.com, whereas the statistical information pertaining to the clean energy sector was sourced from Standard & Poor's global clean energy indices. Once the data were entered into the application, they were organized using Microsoft Excel and subsequently processed prior to analysis. The returns were computed using the formula given below.

Returns = ln (current price/previous price)

Table 1. Indices Details

S. No.	Indices	Time Span
1.	OSE	1-12018 to 31-12-24
2.	NYSE	1-12018 to 31-12-24
3.	SSE Composite	1-12018 to 31-12-24
4.	S&P Global Clean Energy Index	1-12018 to 31-12-24

It should be noted that the data included in the research have a defined time frame, and Table I provides a summary of the clean energy index and stock market indexes for four distinct nations. presents data on the clean energy index, four national stock market indices, and the duration of the study period.

The copula approach is the preferred technique for studying the dependent structure of R-programs. The bivariate copula technique employs the selection of five distinct families of copulas to ascertain the interdependence structure. The subsequent instances are as follows.

3.1 Gaussian Copula

A Gaussian copula represents the dependence structure of a multivariate nominal distribution. A multivariate nominal distribution is created by mixing the Gaussian copula with the nominal marginal distributions, yielding this copula. Becker and Proksch [21] conducted a study in which they established that a Gaussian copula represents a distribution within a unit cube. This distribution can be estimated by employing a typical multivariate approximation technique and implementing a basic modification in the likelihood. The subsequent statement is a mathematical proposition that can be formulated as

$$C^{Gauss}(w) = \sigma R \sigma^{-1}(w_1) \dots \dots \dots \dots . \sigma^{-1}(w_b) \quad (1)$$

3.2 Student-t Copula

The linear correlation coefficient was determined by the Student’s t copula, and the probability of random occurrence was below 30%. The Student-t copula has a higher degree of complexity in terms of its appendages than the Gumbel copula. Park and Gupta [22] argued that the investigation of the student-t copula demonstrates the interdependence of arbitrary variables with extreme values in the distribution. Furthermore, it can be observed that the student-t copula effectively captures dependence at extreme values, whereas the Gaussian copula fails to do so. This highlights the superiority of the student-t copula as a better fit for a given dataset [23]. The subsequent numerical illustration shows the application of the student-t copula in the analysis.

$$C_{(w,x)} = \int_{-\infty}^{\sigma-1(w)} \int_{-\infty}^{\sigma-1(w)} \frac{1}{2\pi.\sqrt{1-\gamma^2}} \frac{a^2-2\gamma ab+b^2}{\exp\{-2(1-\gamma^2)\}da.db} \quad \textbf{(2)}$$

3.3 Gumbel Copulas

The Gumbel distribution was predicted using the Clayton copula. The Gumbel copula exhibits a departure from the conventional behavior of copulas by displaying a stronger focus on the negative tail than on the positive tail. Kole and Koedijk [24] conducted research on the Gumbel copula, which is mathematically represented as follows:

$$\boldsymbol{C_b(w,x,\gamma) = \exp\{-(-1\,k\,w)^2 + [(-1\,k\,x)\gamma\,]\}, \gamma\varepsilon(1,\infty)} \quad \textbf{(3)}$$

If the probability distributions of the two variables conform to the Gumbel copula, it is likely that the two variables are exhibiting simultaneous development [21]

3.4 Clayton Copulas

The concept of asymmetric variation of the Archimedean copula was conceived by Clayton, who subsequently named it the Clayton copula. The Clayton copula serves as an illustrative instance that showcases the general phenomenon of the positive tail exerting a greater influence on the tail than the negative tail. This claim is substantiated by available evidence [21, 24, 25]. The Clayton copula can be mathematically represented by the following numerical expression.

$$\boldsymbol{C_b(w,x,\gamma) = \max\left\{[(w^{-\gamma} + x^{-\gamma} - 1)\frac{-1}{\gamma}, 0]\right\}, \gamma\,\varepsilon\,\{-1,\infty\}\,(0)} \quad \textbf{(4)}$$

3.5 Frank Copulas

The Frank copula, alternatively referred to as the interchangeable copula, represents the correlation structure among multiple random variables. In this exposition, a quantitative depiction of the configuration of the Frank copula is provided for examination.

$$C_{\varphi}^{Qs}(w_1 \ldots\ldots\ldots w_n) = \frac{1}{-\varphi} \frac{\Pi_l(\exp(-\varphi w_1)-1)}{\log(1+\exp(-\varphi)-1)} \quad \textbf{(5)}$$

The Frank copula, alternatively referred to as the interchangeable copula, is a statistical methodology used to estimate the level of correlation among a collection of independent random variables [26]. This study provides a comprehensive numerical analysis of the Frank copulas.

3.6 Spearman's Correlation and Kendell Tau's

Correlation analysis, a statistical method, can be used to ascertain the strength of the relationship between two variables. Power may vary from one to one-and-a-half. Values approaching -1 signify a robust negative correlation, whereas values approaching +1 indicate a significant positive association. As the value approaches -1, the variables demonstrate a flawless inverse correlation [27]. Kendall tau and Spearman correlation tests were used in this study to investigate the correlations between variables. Kendall tau correlation is a nonparametric statistical test. It is widely used to determine the level of dependence between two variables. Spearman rank correlation tests the link between variables [24, 25].

4. Results and Discussion

Table 2 presents a comprehensive analysis of several financial markets, including the Shanghai Composite, New York Stock Exchange, Oslo Stock Exchange, and clean energy markets. Two key aspects that can be identified in descriptive statistics are the measures of central tendency and variability. Both the mean and median serve as illustrations of the measurements of the central tendency. [26] identified several metrics of variability, including the minimum, maximum, standard deviation, and skewness. The indicators of the variable character of returns include the range of possible values for these instruments on any given day as well as the number of minimum and maximum returns [26]. The S&P clean energy index experienced a significant decline of -11.034 percent in its largest single-day loss, but the NYSX composite index achieved a notable increase of 12.597 percent in its largest single-day gain. The utilization of standard deviation is employed for the assessment of several markets, including the Shanghai Composite, New York Stock Exchange, Oslo Stock Exchange, and clean energy market. PSX exhibited the highest standard deviation within the series, measuring 2.818 percent. This characteristic renders it unexpected. The Shanghai Composite exhibited the lowest level of risk among the indices, as evidenced by its standard deviation of 1.101%.

Table 2. Descriptive Statistics

	Shanghai Composite	**NYSX Composite**	**Oslo**	**S & P clean Energy index**
Minimum	-5.554e-02	-0.0956374	-0.0584239	-0.1103455
1st quartile	-5.683e-03	-0.0054407	-0.0065491	-0.0079831
Median	-3.914e-04	-0.0008488	-0.0010064	-0.0009087
Mean	3.441e-05	-0.0003074	0.0005788	-0.0007602
3rd quartile	5.319e	-0.0037862	0.0044085	0.0064716
Maximum	8.039e-02	0.12597750	0.0983197	0.1249760
Standard	0.01101196	0.01224857	0.01123709	0.01666727
Skewness	0.68006434	1.393853	1.309108	0.6003045

Note: Table 2 provides a concise overview of the Chinese, American, Norwegian, and Pakistani stock markets as well as the global renewable energy sector. The act of graphically representing metrics of central tendency and dispersion, such as skewness and standard deviation, along with the mean, median, minimum, and maximum, exemplifies the use of descriptive statistics.

Histograms displaying logarithmic returns can be observed within various financial markets, including the worldwide renewable energy market, Shanghai Composite, New York Stock Exchange (NYSE), Oslo Stock Exchange (OSE), and Paris Stock Exchange (PSX).

Dependence structure between the Chinese stock market and global clean energy market

Table 3. Dependence structure between shanghai composite and S & P clean energy index

Copula	**Initial Parameter**	**Final parameter**	**LOG likehood**	**AIC**	**BIC**	**Tail dependence**	
						Lower	**Upper**
Gaussian	0.505	0.267	46.66	-91.33	-86.17	0.0000	0.0000
t-student	0.267	0.269	49.84	-95.68	-85.36	0.0101	0.0101
Gumbel	1.212	1.190	46.74	-91.48	-86.32	0.0000	0.2095
Clayton	0.424	0.424	23.51	-45.03	-39.87	0.1956	0.0000
Frank	NA	1.647	45.22	-88.44	-83.28	0.0000	0.0000

The table estimates the starting and end copula parameters, log likelihood, Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC).

To examine the correlations between the Chinese stock market and renewable energy industry, we employ the copula with the lowest Akaike Information Criterion (AIC) value. According to the findings presented in Table 3, it can be observed that the T-Student copula demonstrates superior accuracy, as evidenced by its AIC value of -95.68237. The Student's t-test copula was employed to study the tail length of the dependent pattern. The t-Student copula, with 13,6875 degrees of freedom, sheds light on the significant tail dependence observed between the two return series.

Dependence pattern among NYSX and s & p clean energy index

Table 4. Estimates of dependence pattern among NYSX and s & p clean energy index

Copula	**Initial Parameter**	**Final parameter**	**LOG likehood**	**AIC**	**BIC**	**Tail dependence**	
						Lower	**Upper**
Gaussian	0.250	0.583	264.12	-526.24	-521.08	0.0000	0.0000
t- student	0.583	0.584	321.99	-639.98	-629.67	0.3660	0.3660
Gumbel	1.659	1.660	286.58	-571.17	-402.79	0.0000	0.4817
Clayton	1.318	1.319	202.39	-397.63	-337.21	0.5912	0.0000
Frank	NA	4.289	246.32	-409.64	-485.48	0.0000	0.0000

Note: The table displays all copula parameters, including the initial and final values, log-likelihood, Alike Information Criterion (AIC), Bayesian Information Criterion (BIC), and tail dependency between the New York Stock Exchange composite and the S&P Global Clean Energy Index.

Table 4 demonstrates that the t-student copula is the most suitable for assessing the reliance between the U.S. stock market and the renewable energy market since it possesses the lowest AIC value among all copulas. The observed dependency exhibits symmetrical upper and lower tails, indicating a parallel fluctuation pattern between the returns on the U.S. stock market and the renewable energy market. This observation is supported by the presence of symmetric upper and lower tails in dependence. The correlation between the U.S. stock market and renewable energy has a degree of freedom of 0.0000000, suggesting a significant link between these two variables.

Dependence pattern among pattern Oslo and s & p clean energy index

Table 5.

Copula	Initial Parameter	Final parameter	LOG like hood	AIC	BIC	Tail dependence	
						Lower	Upper
Gaussian	0.5056	0.4445	139.3821	-276.764	-271.607	0.0000	0.0000
t- student	0.5056	0.4416	157.9639	-311.927	-301.610	0.173981	0.173981
Gumbel	0.290335	1.402	152.8104	-303.620	-298.462	0.0000	0.087508
Clayton	0.818233	0.8182	85.44145	-168.88	-163.72	0.42863	0.0000
Frank	NA	2.889	127.0157	-252.03	-246,87	0.0000	0.0000

Table 5 shows that the t-Student copula is most suitable for analyzing the relationship between the renewable energy industry and the Canadian stock market. The copula has an AIC value of -311.9278, which supports this conclusion. Table 5 shows that the t-student copula is an ideal choice. The study's findings show that the dependence has symmetrical upper and lower tails, indicating that the returns on the Oslo stock market and the renewable energy market fluctuate with a similar frequency. Renewable energy and the Oslo stock market have a statistically significant relationship, as indicated by Student's t-test with 0.0000 degrees of freedom.

4.1 Spearman Correlation

Table 6. Estimates of spearman correlation

	SC	NYSC	Oslo	S&P Clean
SC	1	nil	nil	0.249648
NYSC	nil	1	nil	0.505596
OSLO			1	0.063241
PSX				
S&P Clean	0.249648	0.65358	0.505596	1

The results of the Spearman correlation analysis, as depicted in Table 6, indicate that there is no significant relationship between the renewable energy market and the Shanghai Composite, New York Stock Exchange, or Oslo Stock Exchange. The aforementioned findings are presented within the framework of table. This empirical evidence supports our perspective, which posits that there is no overtly discernible pattern of interdependence among different stock markets. Based on the data provided in the table, there appears to be a discernible correlation between the fluctuations observed in the renewable energy market, Oslo Stock Exchange, Shanghai Composite, and New York Stock Exchange. This suggests that alterations occurring in the initial market will also impact subsequent markets.

Kendell tau result

Table 7. Estimates of Kendell tau test

	SC	NYSC	Oslo	PSX	S&P Clean
SC	1	nil	nil	nil	0.175211
NYSC	nil	1	nil	nil	0.397404
OSLO			1		0.290335
PSX				1	0.028757
S&P Clean	0.175211	0.397404	0.290335	0.028757	1

The information pertaining to Oslo, the S&P renewable energy index, the Shanghai composite, and the New York Stock Exchange (NYSE) composite is presented in Table 7. The results obtained from the implementation of the copula technique indicate a limited degree of link between the two variables, which aligns with the findings of Kendell's tau correlation analysis that also identified a weak relationship. This study concludes that the renewable energy market exhibits a dependent structure and demonstrates a negative correlation with the Shanghai Composite, New York Stock Exchange, and Oslo Stock Exchange. This conclusion was derived from the information presented in this study.

4.2 Discussion:

Zhang, Zhao [28] Suppose that the impact of the energy sector on the stock market is a fundamental question in the field of energy economics. This investigation provided findings of equivalent relevance. The conclusions of this study can help policymakers and investors understand swings in the global stock market, thereby allowing for better risk assessment and management approaches.

To accomplish this goal, we combine the daily returns of the renewable energy index with the daily returns of the US, Norwegian, and Chinese stock market indices from January 1, 2018, to December 31, 2024. This study used a copula family to allow researchers to measure the dependent structure. Tail dependency is analysed using a variety of copulas, including Gaussian, Student-t, Gumbel, Clayton, and Frank. The model with the lowest Akaike Information Criterion (AIC) is predicted to provide the best representation of the copula family. Because of the asymmetry of the data, the student-t copula was selected as the best model for all possible data-series combinations.

According to Sukeda and Sei [26], the student copula exhibits the same upper and lower tail marginal behavior as a series. This represents the current situation. The connection between the renewable energy index and Chinese Shanghai Composite Index has been found to have a robust positive relationship, but the correlation between the two indices has been observed to decline over time. Both the upper tail reliance and the lower tail dependency exhibit a value of 0.0110052. The pair exhibiting the lowest correlation is comprised of the renewable energy index and the Pakistan Stock Exchange (PSX). The tail dependency ranged from 6.203291 to 0.1161771, with a maximum value of 0.1161771.

5. Conclusions

Based on the copula study findings, interdependence exists among the renewable energy markets in the United States of America, China, and Norway. However, this connection is tenuous. The results of this analysis align with the findings of a comparable study conducted in China by [28]. This analysis focused on the inclusion of three countries and one clean energy indicator. There is a need to incorporate an international perspective into future research endeavors. The inclusion of more countries in the analysis, particularly by comparing economically developed nations with emerging economies, has the potential to yield insightful findings. Moreover, Vine copulas have the potential to be employed in future research endeavors aimed at examining conditional dependence. This study employs a copula approach to examine the extent of interdependence between two distinct markets.

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Conflicts of Interest

The author confirms that there are no conflicts of interest.

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