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Dependence Structure between clean energy market and stock markets: Evidence from Copula Approach

Dr. Irfan Ullah Munir *
Assistant Director, University of Management Science, PMAS–Arid Agriculture University Rawalpindi, Pakistan
Irfan.munir@uaar.edu.pk

Dr. Farida Faisal
Director, University of Management Science, PMAS–Arid Agriculture University Rawalpindi, Pakistan
farida.faisal@uaar.edu.pk

Dr. Anum Shafique
Lecturer, University of Management Science, PMAS–Arid Agriculture University Rawalpindi, Pakistan
Anum.shafique@uaar.edu.pk

* Corresponding Author

ABSTRACT

This study examines the dependence structure between the clean energy market and the stock markets of Pakistan, United States, China, and Norway. It employes daily data from 2017 to 2022 and used copula model for the purpose of analysis. The findings of the study show that t-copula provides the best fit for all the market pairs. This shows that the presence of tail dependence between the bivariate pairs of clean energy market and the stocks. However, the study further highlights that the dependence is stronger in the developed markets and relatively weaker in Pakistan. The study highlights implications for investors and policy makers.

Keywords: Copula, renewable energy, stock markets, dependence structure, portfolio.

INTRODUCTION

Climate financing represents a critical domain in the contemporary global landscape. Global events, such as world climate conferences under the United Nations Framework Convention on Climate Change, have made this clear (Liu et al., 2021). Clean energy is intrinsically linked to climate financing. Conversely, a nation's stock market serves as a significant indicator of its economic progress.

The price of oil and gas is a primary element influencing market trends. Kilian (2008) asserts that rising crude oil prices impede economic growth and heighten inflation expectations in the short term. The rising prices and declining profit margins of corporations in profit generating adversely affect the stock markets. Kilian (2009) asserts that rising oil prices adversely affect stock prices and economic activities. Conversely, a different trend emerges when focusing on the utilization of clean energy sources. A study conducted by Wen et al. (2012) identified a correlation between stock markets and energy markets. Clean energy encompasses renewable and sustainable options for electricity generation, as opposed to costly fossil fuels that adversely impact the environment.

The aforementioned circumstance clearly demonstrates that the clean energy market significantly influences the dynamics of the stock market, particularly as evidenced by the research conducted by Wen et al. (2012) on this correlation. Nevertheless, there is a paucity of research addressing the directional connection between the markets. Furthermore, the study has assessed the stock markets of countries that are actively implementing sustainable energy measures. The study's conclusions may serve as an impetus for other countries to emulate, as a primary deterrent to adopting renewable energy initiatives is the elevated costs relative to conventional projects. Furthermore, only a single market from the developing nations has been selected to investigate the potential correlation or contagion between stock markets and the clean energy sector. This study use worldwide indices for renewable energy markets. Finally, a study by Kocaarslan and Soytas (2021) indicates the necessity of examining the volatility patterns in the clean energy market and their influence on stock markets. Furthermore, a research study by Liang et al. (2021) considers seven global economic aspects alongside five uncertainty indices to assess the volatility patterns of clean energy and natural gas through these indices. Minimal research has been conducted on cross-market analysis.

This study investigates the dependency structure between the worldwide S&P clean energy index and certain international stock markets to fill the current gaps in the literature. The study specifically examines the correlation between the clean energy market and the stock exchanges of Pakistan (PSX), the United States (New York Stock Exchange), China (Shanghai Composite Index), and Norway (Oslo Stock Exchange). The investigation aims to ascertain if these stock markets demonstrate dependency on the global clean energy industry and whether the intensity of this relationship differs across established and emerging economies. The study utilizes copula-based models to elucidate nonlinear and tail dependency interactions among various marketplaces. The results are anticipated to yield valuable information for investors and regulators concerning risk transmission, portfolio diversification, and the increasing interconnection between clean energy markets and global financial markets.

LITERATURE REVIEW

Theoretical Literature:

Markowitz's portfolio theory (1952) posits that investors adopt a risk-averse strategy, seeking to maximize profit while minimizing risk. It is a strategy for selecting investments to achieve substantial returns while maintaining an acceptable level of risk. This underscores the significance of portfolios, diversification, risks, and the interrelations among various markets and assets. Consequently, it may be contended that investing in the securities of the clean energy sector would pose a lower risk for the investor aiming to construct a portfolio. Kahagalle and Jones (2021) assert that the green bond market, which invests in climate assets, exhibits lower credit risk in energy and bond markets. Consequently, investment in such a market provides investors with an optimal portfolio.

Empirical Literature Review:

According to Henriques et al., (2008) examined correlation between prices of oil and alternative energy stock indices and claimed that energy companies function like high technologies businesses. They establish stock prices have a greater technology symbols on US stock prices like clean energy and oil prices using Granger causality test and the LA-VAR model.

According to Liu et al., (2021) they basically studied the clean energy markets and green bonds and investigated dependence and systematic risk spillover in these markets. The research study determined the time-varying copula and constructed conditional value risk model to measure dependence between these markets. The clean energy and green bonds indicates positive time-varying tail dependence. The existence of clean energy markets is determined the pattern of risk spillover is from(to) green bonds to(from) clean markets. The time period of the duration is 5 July 2011 to 24 February 2020. The empirical analysis of the research study indicates positive time-varying dependence between clean energy markets and green bond market. Moreover, clean energy markets have a spillover effect on green bond market and possess a extreme upward and downward movements and vice versa. The data of research study is derived from Bloomberg database. The results of research study add valuable contribution to policy makers and investors by adding undetermined tail losses.

According to Tiwari et al., (2021) they basically determined the risk between oil and clean energy and technology companies and deeply examined dependence and systematic risk. Their research study used dependence switching copula model that represents four different markets. The negative and positive correlation exist and tail dependence was totally asymmetric between these markets. The tail dependence determined weak between clean and oil market. The research paper represents the tail and dependence between stock returns and oil prices of 54 clean energy companies and 100 technology companies and used four market conditions like bullish, bearish WECI, low oil price or high oil price. The findings of research study indicate positive correlation regimes under asymmetric and negative correlation regimes under symmetric dependence. The tail dependence is lowest between clean energy and oil market under positive correlation, and lowest and possess negative correlation between oil and technology indices. The results of research study provide clear insights to investors and portfolio managers to manage risk opportunities in difficult time period.

According to Bhutta et al., (2024) the purpose of research study indicates the dependence structure between clean energy markets and green bonds market. For this research study the dependence pattern has been tested by copula families like t-copula, frank copula, Gaussian copula and Gumbal copula. The final results of the research study indicate dependence pattern exist in all pairs. The selection of the model like best-fit copula is used to measure direction between dependence structure between these markets. The findings of the paper are beneficial for investors and policy makers.

According to Sadraoui et al., (2025) their research study examines the risk spillover and dynamic dependence structure between Brazil, China, South Africa, Russia, and India stock markets and energy commodities. The research study determines or used copula-based multivariate Garch model or M-Garch model to explore conditional correlation by different copula models. The research study findings refer positive dynamic dependency among crude oil markets like natural gas and stock markets like BRICS countries. The major findings of the research study support the risk spillover significant effect between BRICS stock markets and crude oil market. The existence of the volatility spillover among BRICS stock markets, natural gas prices, and oil prices increase volatility forecast in stock markets. Moreover, investors take natural gas and oil markets to improve their portfolios and hedging strategies.

According to Zeng et al., (2026) their research study determined or assess the volatility connectedness or dependence structure among Russia-Ukraine war and Covid-19 crises and their influence on crude oil, developed markets, cryptocurrencies and equity markets on china and ASEAN countries, the analysis of the research study is divided into three parts like during covid-19, pre-covid-19, and Russia-Ukraine war. The research study basically occupied the GARCH, vine copula, QVAR (quantile vector auto regression), and extreme value theory for analysis of results. The findings of the research study from these models indicates significant lower tail connectedness due to outbreak of covid-19 pandemic. Moreover, the impact Russia-Ukraine war on stock markets of ASEAN and china countries are overestimated. However, portfolio analysis between china and ASEAN countries indicates high level of hedging effectiveness between crude oil, cryptocurrency and MSCI developed markets index. In the last investors feel safe haven assets in Chinese and ASEAN equities markets.

According to Mensi et al., (2026) their research study determines or explores risk spillover between G7 stock markets and green bond during and pre coronavirus and Russia Ukraine war period. The research study used copulas and conditional value risk models to determine risk spillover and tail dependence between stock markets and green bond. The findings of the research study indicate the average dependence between stock markets of Germany, Italy, UK, France, and Canada. The dependence structure between green bonds is dependent on US stock markets during bullish market situation. The findings show the evidence of bidirectional risk spillover during first wave of coronavirus. However, the zero tail dependence is observed between green bond and Japan market during Russia-Ukraine war tension. Overall research findings have direct repercussions on portfolio management and funds allocation.

According to Naifar & Alhashim., (2025) they studied or investigates, clean energy, financial transition and biodiversity among tail dependence using partial correlation-based network approach. The research study captures eleven indices from 2019 to 2025, and capture accurate dynamic connectedness across extreme market conditions. The empirical findings of the research study indicate central hub of connectedness like clean energy assets. The research study adopts novel connectedness framework for research study, and used standard Pearson correlation co-efficient by linking co-movements between asset return series. The findings indicate strong higher connectedness in the tails of mean dependence. The future research extend framework such as biodiversity credits or assess spillover cross-border biodiversity finance.

According to Naeem et al., (2021) their research study determined the tail dependence analysis between green bonds and energy markets using time varying optimal copulas and portfolio implications. The research study determines extreme tail linkage or dependence between five energy and green bonds. The research study used or determined time-varying optimal copula model. The findings indicate the negative tail dependence between crude oil, heating oil, gasoline and green bonds. The research study finds positive tail dependence between natural gas and green bonds.

Bondia et al. (2016) investigated the relationship between the stock prices of renewable energy firms, oil prices, technological companies, and exchange rate factors utilizing the structural break co-integration method. They identified significant short-term causal relationships between energy stock prices and macroeconomic variables. The network connections between fluctuations in renewable stock energy prices, influenced by the financial market and politics, were established (Lundgren et al., 2018). Ferrer et al. (2018) advanced the research by utilizing a temporal dynamic frequency analysis technique to examine the interrelationship of renewable energy sources.

Upon considering the impact of financial factors and the volatility of these variables, they found that energy stock prices were closer to technical benchmarks than those of two other energy sources. The influence of economic policy volatility or uncertainty on financial markets, particularly on oil exchange and the energy industry, is examined through risk distribution and tail dependence using the CoVaR methodology (Ji et al., 2018).

It is essential to construct a clean energy market, including wind and solar energy, through the implementation of energy market legislation in response to the ongoing energy crisis and the volatile oil prices (Phan, 2019). To ensure a better, healthier, and more prosperous future for the globe, the development of renewable clean energy sources must be earnestly prioritized in this age of increasing global warming and depleting fossil fuel reserves. The energy generation from fossil fuels adversely affects plants by inducing severe droughts, indicative of insufficient food and clean water supplies on Earth.

Pandemic hit of 2019 also one of the critical points to think about the alternative of the production of clean energy sources where less human invention is required to produce the energy. It was very difficult to manage the labor force for producing electricity because of the policy of 50 percent strength allowed to come to work. During this pandemic economic activity were slow down and significant reduction in energy consumption on global level. Understanding the interactions between clean energy sector and fossil fuel is important for investors and policymakers to determine risk exposure, assess viability of investing in energy clean companies, and assess viability by using renewable energy sources.

Return volatility holds greater significance for market participants than for enterprises in the clean energy sector. This arises from the fact that assessing the volatility of clean energy equities impacts portfolio analysis, asset pricing, and risk management, while not diminishing the importance of regulators and policy indicators who must formulate appropriate legislation for energy transition. Kocaarslan and Soytas (2021) underscored the need of understanding the risks associated with clean energy equities. Surprisingly, there is a deficiency in study into the various factors affecting the volatility patterns of clean energy market shares.

Bhutta et al (2024, studied the dependence structure between green bonds market and the clean energy markets and used copula method to understand the nature of relationships. Zainab et al, (2022) studied the dependence between Green bond market and the Asian stock markets and found that two tail dependence exists in the bi-variate copulas, however the study was limited to India, China and Pakistan only, highlighting the need to further this area of research. Therefore, the underlying study contributes to the literature by testing dependence between clean energy market and the stock markets.

RESEARCH METHODOLOGY

Data Description:

Underlying research study takes into account dependence structure between clean energy market indices and stock indices of Pakistan, the United States, China and Norway. Therefore, secondary data from the major stock indices of these countries were collected. Data for stock indices was sought from investing.com while the clean energy market data was sought from S&P Dow Jones indices. Daily closing prices were used for all indices for the period starting from 30 June 2017 to 2 June

2022. The dataset includes the PSX (Pakistan), Oslo (Norway), New York (USA), Shanghai (China) and Global S&P clean energy market index. The selection of economies is based on their diverse economic structures and varying level of clean energy development to make a comparative assessment of the dependence structures across developed and developing markets. This shows how clean energy dynamics interact with difference economic and policy environments.

Returns were computed from the closing prices using the following standard formula:

Methodology:

Copula:

In order to model the multivariate relationships, there is a substantial body of literature in risk management that highlights the use of copula functions. These copulas are advantageous because allow to select appropriate dependence structure for the series (Shafique et al, 2021) they facilitate in constructing joint multivariate distributions from individual marginal distributions. The models based on copula technique are flexible and provide accurate representation of complex multivariate behavior (Ahmed et al, 2021).

Copulas tend to examine joint behavior between variables by changing marginal distributions in to constant marginal distributions. Due to this, any multivariate distribution can be assessed into distribution marginal and linked through copula model.

The equation of this factor can be determined as follows:

$$K\left(K1 \ldots\ldots\ldots K_L : P_1 \ldots\ldots\ldots\ldots P_{L,ab}\right) = B(K\left(Z_{1,}P_L\right) \colon \varphi_d \qquad (1)$$

In Equation (1), $K_1 \ldots K\_L$ are the variables, B denotes the copula, and φ_d is the dependence parameter.

The Joint bivariate distribution and density can be measured as:

The Joint bivariate distribution and density can be determined as:

$$\left(Z_{1,}Z_{2,}\mu_1, \mu_2, \varphi_d\right) = \theta^2 \left(K_1(Z_1; \mu_1), K_2(Z_2; \mu_2); \varphi_{d/\mu}Z_{1,\mu}Z_2\right. \qquad (2)$$

$$k(Z_1, Z_2, \mu_1, \mu_2, \varphi_d) = B(K_1(Z_1; \mu_1), K_2(Z_2, \mu_2) \colon \varphi_d). \alpha^2_{(n=1)\ kn(y_{(n:)}\varphi_d)} \qquad (3)$$

If $B(\omega_1, \omega_2; \varphi_d = \theta^2 K(\omega_{1,}\omega_2, \varphi_{\underset{\vartheta}{d}})\omega_{1\vartheta}\omega_2$

The log-likelihood of the joint distribution is:

$$logk(Z_1, Z_2, \mu_1\mu_2) = logB(K_1(Z_1; \mu_1), K_2(Z_2; \mu_2); \varphi_d) + \sum 2_{(n=1)}\ logk_{(n)(yf,\varphi_d)} \qquad (4)$$

$$N\left(\mu_1, \mu_{2,\varphi_d}\right) = N_D(\varphi_d) + \sum 2_{(n=1)}(N_L)$$

Parameter estimation follows the IFM (Inference Function for Margins) method.

First, marginal parameters are estimated using maximum likelihood:

This factor can be measured as

$$\mu_1 = arg \max \sum O_{(O=1)} \log k_1 \left(z_1, o,\right. \qquad (5)$$

$$\mu_2 = \arg max \sum O_{(o=1)} \log k_2 \left(z_{2,o,m2}\right) \qquad (6)$$

Then copula parameter is estimated by using:

$$\varphi_d = \arg max \sum O_{(o=1)} \log D \left(\theta_1, o, \varphi_d\right) \qquad (7)$$

Selection of Model is dependent on Akaike Information Criterion (AIC):

$$AIC = -2(\log - likilihood + L) \quad (8)$$

Bivariate copulas:

Bivariate copulas are used to examine any asymmetric behavior in the financial date. According to Raza et al., (2021) it allows precise modeling of dependence between two variables.

Copula families:

There are two main families of copula. One is copulas elliptical that covers Student-t and Guassian other is copulas Archimedean which covers Clayton, Gumbel and Frank copula. These families include both symmetric and asymmetric tail dependence.

Gaussian copula:

This is based on the multivariate normal distribution.

It could be written as follows,

$$C^{Gauss}(w) = \sigma R \sigma^{-1}(w_1) \dots \dots \dots \dots . \sigma^{-1}(w_b) \quad (10)$$

Student-t Copula:

T student copula studies stronger tail dependence. Mathematically, student-t copula could be determined as follows,

$$C_{(w,x)} = \int_{-\infty}^{\sigma-1(w)} \int_{-\infty}^{\sigma-1(w)} \frac{1}{2\pi.\sqrt{1-\gamma^2}} \frac{a^2-2\gamma ab+b^2}{\exp\{-2(1-\gamma^2)\}da.db} \quad (11)$$

Gumbel copulas:

Gumbel copula examines the upper tail dependence. (Raza et al., 2021). Mathematically, Gumbel copula be shown as,

$$C_b(w,x,\gamma) = \exp\{-(-1\,k\,w)^2 + [(-1\,k\,x)\gamma\,]\}, \gamma\varepsilon(1,\infty) \quad (12)$$

If Gumbel copula follows the distribution of two irregular factors, then there is strong probability of two variables increasing at same level of time. (Shafique et al. 2021)

Clayton Copulas:

Clayton Copula emphasizes lower tail dependence. Numerically, copula clayton can be shown as,

$$C_b(w,x,\gamma) = \max\left\{[(w^{-\gamma} + x^{-\gamma} - 1)\frac{-1}{\gamma}, 0]\right\}, \gamma\ \varepsilon\ \{-1,\infty\}\ (0) \quad (13)$$

Frank Copulas:

Frank Copula models symmetric dependence. Mathematical structure of copula frank can be determined as follow:

$$C_{\varphi}^{Qs}(w_1 \dots \dots \dots w_n) = \frac{1}{-\varphi} \frac{\Pi_l(\exp(-\varphi w_1)-1)}{\log(1+\exp(-\varphi)-1)} \quad (14)$$

Spearman's correlation and Kendell tau's:

The parameters of spearman's rho and Kendall's tau are used to investigate correlation strength and direction between variables, the range of values lies from -1 to +1.

RESULTS

Descriptive Statistics:

Table 1 showcases the central mean tendency via median and mean and changing via maximum, minimum, volatility and skewness. Maximum and minimum returns indicate the range of daily fluctuations in the prices of each market. Further, the NYSX recorded the highest one-day gain of 12.597% whereas the substantial one-day decline experienced by Global S&P energy clean market index was -11.034%. The values of Standard Deviation for each series show that market risk. Among all the markets, PSX shows the greatest volatility with a standard deviation of 2.81% which shows that it is riskiest among the other series. On the other hand, Shanghai composite shows lower standard deviation i.e. 1.101% indicating relatively stable return behavior. Over all these results provide sufficient justification to apply copula methodology to capture non-linear and tail dependent relationships.

Table 1: Descriptive Statistics

	Shanghai Composite	NYSX Composite	Oslo	PSX	S & P clean Energy index
Minimum	-5.554e-02	-0.0956374	-0.0584239	-0.0992375	-0.1103455
1st quartile	-5.683e-03	-0.0054407	-0.0065491	-0.0137629	-0.0079831
Median	-3.914e-04	-0.0008488	-0.0010064	0.0015873	-0.0009087
Mean	3.441e-05	-0.0003074	0.0005788	0.0008785	-0.0007602
3rd quartile	5.319e-03	0.0037862	0.0044085	0.0157981	0.0064716
Maximum	8.039e-02	0.1259775	0.0983197	0.1094566	0.1249760
Standard	0.01101196	0.01224857	0.01123709	0.02818276	0.01666727
Skewness	0.68006434	1.393853	1.309108	-0.09852342	0.6003045

Note: Table 1 indicates descriptive statistics for global clean energy and stock indices (China, USA, Norway, Pakistan). Descriptive statistics show skewness, standard deviation, mean median, minimum and maximum values.

Dependence structure between Global clean energy market and China stock market:

Table 2: Dependence structure between S & P clean energy index and Shanghai composite.

Copula	Initial Parameter	Final parameter	LOG likehood	AIC	BIC	Tail dependence	
						Lower	Upper

Guassian	0.51	0.27	-91.3	-86		0	0
t-student	0.27	0.27	49.8	-96	-85.3	0	0
Gumbel	1.21	1.19	47	-91.4	-86.3	0	0.21
Clayton	0.42	0.42	24	-45	-39.9	0.195	0
Frank	NA	1.64	45.2	-88.44	-83.29	0	0

Note: The table provides results of various parameters of copula, including starting and final parameters, log-likelihood, Alike Criterion Information (AIC), and Bayesian Criterion Information (BIC), and tail dependence between Global S&P clean energy Index and shanghai composite.

The above table shows the dependence between two series i.e., Shanghai composite and Global S&P clean energy market index using various copulas. The findings refer that t-student copula presented lowest value of AIC (-95.68237), indicating the best fit for this pair. Further, it is important to highlight that t-Student copula captures heavy-tail characteristics. The estimated tail dependence values which are 0.011 for both the upper and the lower tails indicate extreme movements in the Chinese stock market which are likely to coincide with co- movements in clean energy market. The research results show weak but significant tail dependence, signaling that co-movements intensify during volatile periods.

Table 3: Estimates of dependence structure pattern between NYSX and S&P clean energy market index:

Copula	**Initial Parameter**	**Final parameter**	**LOG likelihood**	**AIC**	**BIC**	**Tail dependence**	
						Lower	**Upper**
Gaussian	0.25	0.58	264	-526	-521	0	0
t-student	0.58	0.58	321.99	-639.99	-629.67	0.366	0.366
Gumbel	1.66	1.66	286.5	-571.1	-566.01	0	0.48
Clayton	1.32	1.32	202.39	-402.79	-397.63	0.59	0
Frank	NA	4.28	246.3	-409.64	-485.48	0	0

Results in the above table show that t-student copula provides best fit for NYSX and clean energy market index, with smallest AIC value (-639.9898). Further, lower and upper tail dependence numbers are equal to 0.366 showing stronger dependence compared to the Chinese market. This symmetry shows that both positive and negative symbols or shocks in US stock indices are transferred to clean energy market at a similar intensity. Moreover, the interconnected nature of US and clean energy sector is also affirmed by the presence of substantial tail risk co-movement highlighted by the degree of freedom parameter.

Table 4: Estimates of dependence structure behavior Norwegian Stock Market and S&P Clean energy market index:

Copula	Initial	Final	Log likelihood	AIC	BIC	lower	upper
Gaussian	0.5056	0.4445	139.3821	----- (276.7642)	- (271.6057)	0	0
Tstudent	0.5056	0.4416	157.9639	-311.9278	-301.6108	0.173981	0.173981
Gumbel	0.290335	1.402	152.8104	-303.6209	-298.4624	0	0.087508
Clayton	0.818233	0.8182	85.44145	-168.8829	-163.7244	0.42863	0
Frank	NA	2.889	127.0157	-252.032	-246,873	0	0

Note: The table provides results of various parameters of copulas, including starting and final parameters, log-likelihood, Alike Criterion Information (AIC), and Bayesian Criterion Information (BIC), the dependence tail between the OSLO and S&P Global clean energy market index.

The above table indicates that dependence structure between two markets is best captured by student t- copula with lowest AIC -311.9278. The lower and upper tail dependence value is 0.1739, implying moderate and symmetric dependence. It shows that the fluctuations in both the markets ae tend to be similar, although with less intensity than observed for the U.S. Market.

Dependence structure between clean energy market and Pakistan stock market:

Table 5: Estimate of dependence structure pattern between PSX and S&P Clean energy index:

Copula	Initial Parameter	Financial parameter	Log likelihood	AIC	BIC	Tail dependence	
						Lower	Upper
Gaussian	0.5055957	0.5168	1.685335		-1.370669	3.787845	0

0							
t-student	0.5168	0.4637	10.26016	-16.52032	-6.203291	0.1161771	0.1161771
Gumbel	1.029415	1.041	5.6657	-9.331401	-4.172887	0.00000000	0.5386095
Clayton	0.05883054	0.05883	1.902899	-1.805798	3.352716	7.639289	0.000000
	e-06	e+00					
Frank	NA	0.2613	1.178786	-0.3575727	4.800941 0	0	

Note: The table provides results of various parameters of copulas, including starting and final parameters, log-likelihood, Alike Criterion Information (AIC), and Bayesian Criterion Information (BIC), and the dependence tail between PSX and the S&P Global clean energy Index.

The above table shows that copula t-student provides best fit with the AIC smallest value that is -6.2023 for PSX and clean energy index. Tail dependence however shows weak but measurable association with the value of 0.11617 for both tails. The degree of dependence for PSX is lower as compared to the other markets, which suggests limited integration between PSX and the global clean energy sectors. However, the presence of non-zero tail dependence shows that non-integration does not mean that it is safe from the impact of extreme market movements. The effect of such extreme market movements may still be transmitted to some extent.

Table 6: Estimates of spearman correlation

Copula	SC	NYSC	OSLO	PSX	S & P
SC	1				0.25
NYSC		1			0.65
OSLO			1		0.5
PSX				1	0.06
S & P					1

Table 6 presents the results of the Spearman correlation, indicating that no substantial connection exists between the Shanghai Composite, NYSX, PSX, Oslo stock markets, and the clean energy market, hence reinforcing our conclusion regarding the copula dependency structure among the stock markets. The data in this table indicate that the Shanghai Composite, NYSE, PSX, Oslo Stock Exchange, and the clean energy market exhibit correlated movements, signifying that a fluctuation in one market will precipitate a variation in another.

Table 7: Measure of Kendell tau test

	Shanghai Composite	NYSX Composite	Oslo	PSX	S & P clean Energy index
Shanghai 1	-	-	-	0.1752112	
Composite	-	1	-	-	

0.3974035					
NYSX	-	-	1	-	0.2903354
Oslo-PSX		-	-	1	0.028757474
S & P clean	0.1752112	0.3974035	0.290335	0.028757474	1

Table 7 presents the outcomes for the Shanghai Composite, NYSE Composite, Oslo, PSX, and S&P Clean Energy Index. Kendall's tau correlation reveals that the relationship between these variables or markets is notably tenuous, supporting our conclusion derived from the copula approach. This research study concludes that the relationship among the Shanghai Composite, NYSX, PSX, Oslo stock market, and clean market energy is tenuous, indicating a dependence structure between these stock markets and the clean market energy index.

DISCUSSION:

The link between stock markets and energy is the main concern in energy economics (Wen, Wei, & Huang, 2012). The link is emphasized in the literature as the energy prices, policies, and clean energy transitions impact the stock market behavior directly.

According to market integration theory, the markets become interlinked when they share common economic driver. In that connection, clean energy acts as a shared external factor affecting various economies. This theoretical understanding is confirmed by the study that how stock markets of different countries co-move with clean energy sector. It aids the investors and policy makers to make informed decisions regarding risk and portfolio management.

The objective of research study is determined by using daily returns of stock market and clean energy market index indices for USA, Pakistan, Norway, and China from June 30, 2017, through June 2, 2022. The family of copula was used in this research work to determine the dependent structure. Using the Gumbel, Gaussian student-t, Clayton, and Frank copulas the tail dependence is measured through these families. The best-fitting model for the copula family is that which has lowest AIC. The student-t copula is nominated as the best-fitting model for all pairs of data series due to asymmetry patterns.

The normal lower and upper tail marginal behavior of series indicates student-t copula (Ejaz., 2021). Clean energy index and the Chinese Shanghai Composite Index have the strongest upward and downwards correlation. The values for the bottom reliance and upper dependence tail both indicates 0.0110052. The least tail-dependent pair is the clean energy index and Pakistan Stock Exchange (PSX). The lower dependence tail reliance is 6.203291, and higher dependence tail is 0.1161771.

CONCLUSION:

The copula analysis reveals a reliance structure between the clean energy industry and the United States, China, Pakistan, and Norway. Investors are advised to contemplate the renewable energy sector for investment opportunities and portfolio inclusion. Policymakers are advised to evaluate the impact of the clean energy market sector on the nation's economic growth and stock markets while formulating policies and methods to stabilize dynamic markets, such as equities markets.

The recent research study focused on three countries and one clean energy index. Future studies should involve investigating other countries as well. The inclusion of more countries and a comparison analysis between developed and developing nations may yield more significant results. This work employs a copula approach to analyze the dependency between two marketplaces, whereas future research may utilize Vine copulas to examine conditional dependence. The study can be expanded further by analyzing other stock markets as well and other blocks such as Asian and G7 economies so as to understand the contagion effect on the developed and developing market for further insights.

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