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Dynamic relationships among green bonds, CO₂ emissions, and oil prices

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Green bonds play a pivotal role in the financing of sustainable infrastructure systems. Likewise, CO₂ emissions and oil prices can cause an impact on the green bonds market. In order to better understand this issue, this study analyzes the relationship among green bonds, CO₂ futures' prices, and oil prices using a daily data set that includes 2,206 observations corresponding to daily information from 1 January 2014 to 15 June 2022. The Granger Causality Test and the Dynamic Conditional Correlation (DCC-Garch) Model were employed to conduct this analysis. Furthermore, a sensitivity analysis was performed to identify crisis periods concerning the sample period and provide an analysis of DCC-Garch results during extreme market conditions like the COVID-19 pandemic and the Russian invasion of Ukraine. The Granger Causality Test results present a unidirectional causality running from the Green Bond Index to the oil price returns. Also, there is a unidirectional causality running from the Green Bond Index to the CO₂ futures' returns. Additionally, a unidirectional causality runs from the oil price returns to the CO₂ futures' returns. The results for the DCC-Garch indicate a positive dynamic correlation between the Brent oil price return and the CO₂ futures' returns. Finally, the Green Bond Index shows a negative dynamic correlation to the oil return and the CO₂ futures' returns presenting a strong correlation in uncertainty periods.

KEYWORDS

co-movements, dependence, oil price, green bonds, CO₂ emissions, scientometric analysis

1 Introduction

The energy sector is an essential driver of economic growth due to all the activities involved in the economy's aggregate demand, including power generation, industrial use, transportation, and residential use (Sadorsky, 2009). The power generation sector is growing in terms of energy demand and carbon dioxide emissions, and in the context of global warming, this sector needs to be balanced with future economic and environmental

needs (Sadorsky, 2009). An analysis of trends of CO₂ emissions and their relation with the oil prices and the green bonds market has been proven to be useful for policy-makers and energy policy analysts. Understanding the primary sources of greenhouse gas emissions and the main instruments for their reduction is essential for their worldwide management and climate change mitigation (Quadrelli and Peterson, 2007).

Green bonds play a significant role in financing sustainable infrastructure systems (SIS). This financial mechanism was introduced by the European Investment Bank (EIB) in 2007 as a novel arrangement in response to the growing environmental crisis. It offers characteristic environmental benefits due to its purpose of financing or refinancing green projects, including low carbon, energy-efficient, and climate-friendly projects (Nguyen et al., 2021). In this context, the green bonds and the energy sector have a close connection given by environmental concerns.

According to the standard microeconomics theory, in a Marshallian consumer demand function, the most important determinants for a consumer good are the price of the good, the consumers' income, and the good's substitute price (Marshall, 1890). Thus, in order to model energy demand, it is necessary to postulate a model that involves the price of energy consumption, income, and the prices of a substitute source of energy (Sadorsky, 2009). According to Omri et al. (2015b), it is broadly accepted that renewable energy is a substitute for crude oil in both consumption and production of other energy sources. Therefore, a negative link between oil prices and renewable energy demand is expected because increases in oil prices would encourage businesses and households to reduce consumption, purchase more energy-efficient products and switch to renewable energy sources (Henriques and Sadorsky, 2008). Nevertheless, according to Azhgaliyeva et al. (2022), if a green bond has value as an environmental asset, then a positive correlation is expected between the green bond and crude oil prices. It is likely that when oil prices rise then the renewable energy investment growth, as there is an inclination to substitute away from crude oil for alternative energy, which should lead to the increase in the issuance of green bonds, particularly in oil-importing economies. In contrast, a positive relationship between oil price and CO₂ emissions is expected due to the direct connection between energy demand and carbon dioxide emissions (Sadorsky, 2009). At this point, green bonds, as one of the most important financial eco-innovation mechanisms, play a relevant role in the financing of SIS, particularly renewable energy projects (Mejia-Escobar et al., 2020; Mejia-Escobar et al., 2021).

Literature review shows that oil prices are related to the real economy and the financial markets/assets either directly or via different channels that include stock markets, exchange rates, and firms' investment spending (Filis et al., 2011; Reboredo, 2012; Malik and Rashid, 2017; Melek, 2018). Furthermore, the oil prices effects on the economy can be justified because oil is one of

the most traded commodities in the global financial markets and a crucial raw material for production, transportation, heating, and energy generation (Cherubini, 2010; Salem, 2017). Also, an increase in oil prices can boost the cost of production and, therefore, decrease firms' profits. Consequently, rising oil prices can bring inflationary pressure, reducing the demand for firms' goods and services (Melek, 2018). Based on these concerns, a set of comprehensive studies have been conducted in order to discuss the consequences of oil price effects on investment in the financial stock markets (Omri et al., 2015a; Singhal and Ghosh, 2016; Dutta et al., 2018; Akkoc and Civcir, 2019; Lin and Chen, 2019; Ren et al., 2019; Lamouchi and Alawi, 2020; Civcir and Akkoç, 2021). The main findings show that the relationships between oil price and the different markets are time-varying and the presence of volatility spillover from oil price to the stock markets, increasing the co-movements in periods of oil price turmoils. Besides, the results indicate that volatility spillover from oil prices to sectoral indicators varies significantly. These results reflect the necessity of dynamic macroeconomic policies to manage the spillover effects on volatility. The findings are also helpful for investors since they show that by diversifying and hedging their investment across different sectors would reduce their portfolios' risks (Akkoc and Civcir, 2019; Civcir and Akkoç, 2021).

However, a knowledge gap has been identified despite all the advances in studying the relationships among green bonds with other financial variables such as 1) conventional bonds and commodities (Le et al., 2021; Nguyen et al., 2021), 2) the connectedness with financial markets (Reboredo et al., 2020; Reboredo and Ugolini, 2020; Saeed et al., 2020, 2021; Liu et al., 2021), 3) the relationship with the renewable energy stocks (Tiwari et al., 2021), and 4) as a hedge for carbon market risk (Jin et al., 2020; Ren et al., 2022). To the best of our knowledge, no study in the current literature has provided an in-depth analysis of the co-movements among the green bonds, CO₂, and oil prices, for example (González-Ruiz et al., 2023) suggest analyzing the dynamics correlations among these three variables. Thus, a deeper analysis of this issue will lead to a better comprehension of the evolution of oil prices, thanks to the implementation of instruments that attempted to use sustainable energies during the studied period. According to Marimoutou and Soury (2015) and Ma et al. (2021), this analysis is relevant because oil is a fundamental component of energy prices and an important source of CO₂ emissions.

We make three main contributions to the literature. First, we provide an in-depth scientometric analysis in order to have a better understanding of the relationships between crude oil prices, CO₂ futures' prices, and green bonds. Three research trends were identified and point to matters related to 1) the impact of energy consumption, CO₂ emissions, oil prices, and climate changes on economic growth; 2) political and institutional factors driving renewable energy consumption, and 3) the correlation among different financial assets,

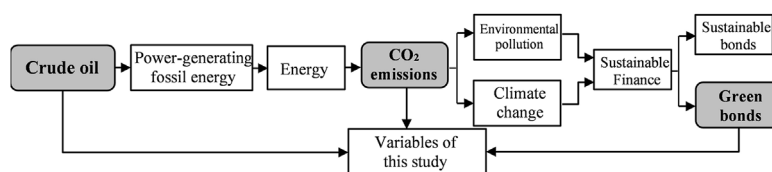


FIGURE 1

Linkages among crude oil, CO₂ emissions, and green bonds. Source: adapted from Ma et al. (2021).

Second, we provide new evidence by examining the dynamic relationship among crude oil prices, CO₂ futures' price, and the green bonds using two models namely, the Granger Causality Test and the Dynamic Conditional Correlation Garch (DCC-Garch)—to provide evidence of the evolution of the linkage between these variables. Third, we bring a month-wise analysis of DCC-Garch results during extreme market conditions like the COVID-19 pandemic and the Russian invasion of Ukraine. Thus, this study provides further insights for decision-makers on designing strategies for promoting eco-friendly policies that contribute to structure sustainable investment portfolios.

The paper is organized as follows. Section 2 presents a systematic literature review of the relationships among green bonds, CO₂ emissions, and oil prices through a scientometric analysis. Section 3 presents the data, the descriptive statistics, and the methodologies used. Section 4 analyzes the results and provides an analysis of DCC-Garch results during extreme market conditions like the COVID-19 pandemic and the Russian invasion of Ukraine. Finally, Section 5 presents the concluding remarks, contributions, and further research.

2 Literature review

For explaining the connection among green bonds, CO₂ emissions, and oil prices, it is necessary to understand their roles. Oil price is the primary indicator in the energy market, and almost all other energy product prices are influenced by it, including natural gas and coal (Ma et al., 2021). Thus, energy prices are correlated with carbon emissions rights and green bonds because this last financial mechanism represents firms' attention to environmental protection, which promotes the development of a low-carbon economy (Wang and Wang, 2022; González-Ruiz et al., 2023). Figure 1 presents the industrial chain connection among crude oil, carbon emission rights, and green bonds. Crude oil

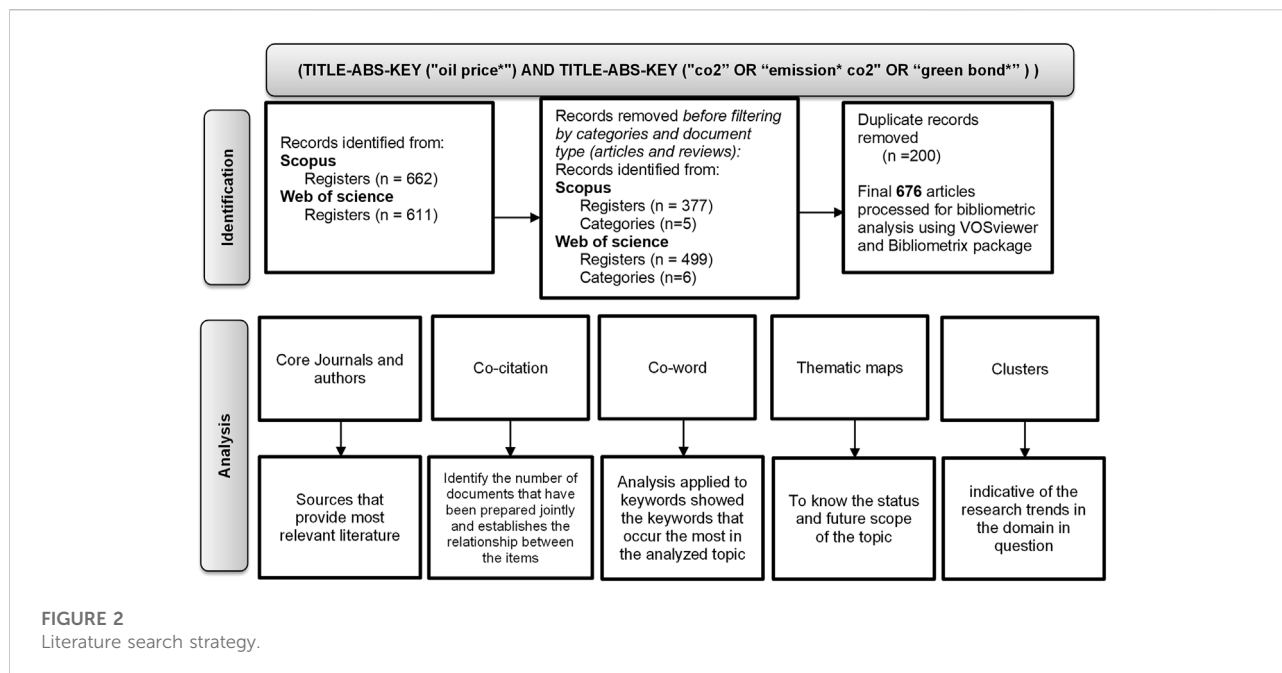
This study undertook a comprehensive and holistic scientometric review of the leading studies about the dynamic relationships among green bonds, CO₂ emissions, and oil prices. Several studies related to sustainability concerns have used this method (Mejía-Escobar et al., 2020; Marquez-Cardenas et al.,

2021; Mejía-Escobar et al., 2021). Due to their stronger academic reputations, the research papers reviewed were obtained from the Scopus and Web of Science (WoS) bibliographic databases. The following keywords were used in both: oil price, CO₂, CO₂ emissions, and green bonds. Thus, the search equation used in both databases was [TITLE-ABS-KEY ("oil price*") AND TITLE-ABS-KEY ("CO₂" OR "emission* CO₂" OR "green bond*")]. After that search, all the research papers were downloaded and indexed into the Mendeley reference manager for further analysis. After removing the duplicates, we used 676 research papers for scientometric analysis using the VOSviewer version 1.6.18 (van Eck and Waltman, 2017) and the Bibliometrix package for R (Aria and Cuccurullo, 2017). Figure 2 shows the literature search strategy.

Then, structural patterns and research trends were identified by employing illustrative diagrams and maps. In this way, three research trends were detected and examined in the scientific literature. Figure 3 presents, on the top, the relationships of the most crucial studies on relationships among green bonds, CO₂ emissions, and oil prices. On the bottom, it shows the three research trends.

The first trend focuses on the effects of factors such as energy consumption, CO₂ emissions, oil prices, and climate changes on economic growth (Naser, 2015; Ftiti et al., 2016; de Souza et al., 2018; Khan et al., 2021). The evidence suggests that energy consumption has a positive long-term impact on economic growth. Thus, energy consumption (i.e., oil or nuclear) has predictive power for economic growth, directly impacting the variation of the real Gross Domestic Product (GDP) in all countries analyzed (Naser, 2015; Ftiti et al., 2016). In this way, in the study conducted by de Souza et al. (2018) for MERCOSUR (for its Spanish acronym of Southern Common Market) countries, they found that energy consumption from renewable sources had a negative impact on CO₂ emissions, while the energy consumption from non-renewable sources had a positive impact. The positive impact of economic development on CO₂ emissions was also observed due to economic activities of all countries reacting to persistent fluctuations in oil prices (de Souza et al., 2018).

In this same line, several studies analyze the links' variations in environmental quality to national economic growth using the Environmental Kuznets Curve (EKC)



analysis. The EKC hypothesis proposes an inverted U-shaped relationship between environmental degradation and economic growth; it has been tested in different countries in the last 2 decades (Moomaw and Unruh, 1997; Balaguer and Cantavella, 2016; Saboori et al., 2016; Alshehry and Belloumi, 2017; Boufateh, 2019; Chen and Taylor, 2020; Erdogan et al., 2020; Moutinho et al., 2020; Akca, 2021). The main variables in the EKC hypothesis are the GDP (Gross Domestic Product) and GDP square; other explanatory variables such as energy, trade openness, urbanization, labor and capital, investment, and foreign direct investment (FDI) were also considered. The results suggest that the EKC model is highly sensitive to omitted variable bias and specific effects in every country (Saboori et al., 2016).

A second trend examines the importance of political and institutional factors driving renewable energy consumption (Adom et al., 2018a, 2018b; Sener et al., 2018; Le and Nguyen, 2019; Lin and Tsai, 2019; Azhgaliyeva et al., 2020; Uzar, 2020; Pata, 2021). According to Uzar (2020), institutional quality positively affects long-term renewable energy consumption. In this way, the analysis conducted by Le and Nguyen (2019) supports the existing direct relationships at the global level among three agendas 1) the use of energy for economic development, 2) energy security, and 3) climate change mitigation. The relations among these three agendas imply that each can be strengthened by referencing the others as integrated themes. However, these topics have been studied as separate themes, ignoring that the business world has become more Interdependent. For this reason, an integrated approach is necessary for progress across the multiple goals for

sustainable development, including providing safe, affordable, and uninterrupted energy sources for all (comprising the poor and vulnerable groups) while fighting climate change.

The third trend delves into the correlation among different financial assets, including financial mechanisms for funding renewable and non-renewable energies (Zaghdoudi, 2017; Le and Nguyen, 2019). In this way, the empirical evidence suggests that the correlation between green bonds and the other studied markets, such as energy prices, especially oil prices (Azhgaliyeva et al., 2021; Yan et al., 2022), and corporate and treasury bonds (Reboredo, 2018; Nguyen et al., 2021) is positive, and negative with stock markets and exchange rates (Naeem et al., 2021). The co-movements are especially strong during financial crisis periods due to the volatility in the financial markets (Le and Nguyen, 2019; Nguyen et al., 2021). Then, as a result, the diversification benefits consequently diminish during times of turmoil. Furthermore, market maturity could explain the positive integration between green bonds and other assets (Le and Nguyen, 2019; Nguyen et al., 2021). In contrast, Zaghdoudi (2017) examines the causal relationship among the OECD (Organisation for Economic Co-operation and Development) countries' domestic oil prices, renewable energy, carbon dioxide emissions, and economic growth from 1990 to 2015. This study also found strong evidence of a negative and significant long-run relationship among oil prices, renewable energy, and CO₂ emissions. The evolution of production technology directly affects the changes in energy consumption.

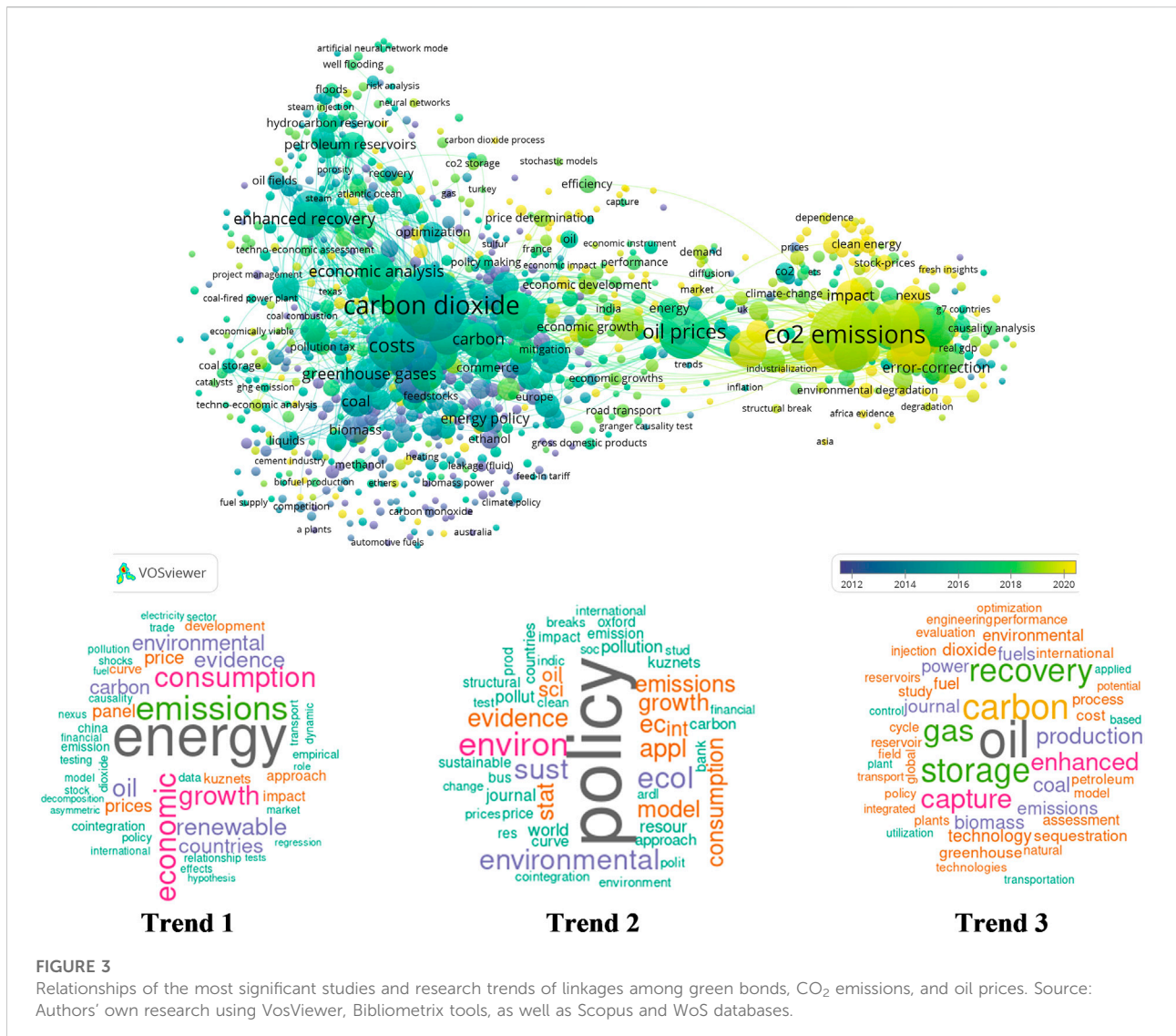


FIGURE 3 Relationships of the most significant studies and research trends of linkages among green bonds, CO₂ emissions, and oil prices. Source: Authors' own research using VosViewer, Bibliometrix tools, as well as Scopus and WoS databases.

The development trends described above generally aim at improving the comprehension of the relationships among green bonds, CO₂ emissions, and oil prices. It is essential to note that the study of the green bonds market has recently increased due to the several world policies that propel more sustainable production. These topics involve several research fields, such as the evolution of technologies and financial markets concerning green project financing and the evolution of strategies for promoting eco-friendly policies. The literature review also shows the absence of studies, including the three variables' analysis. In this context, the simultaneous analysis of the three variables, namely, oil prices, renewable energy, and CO₂ futures' prices allows an understanding of the evolution of the connections among them in time and how the external effects affect their co-movement. Hence, the present study aimed at filling the

knowledge gap on the relationship among green bonds, CO₂ futures prices, and oil prices.

3 Data and models

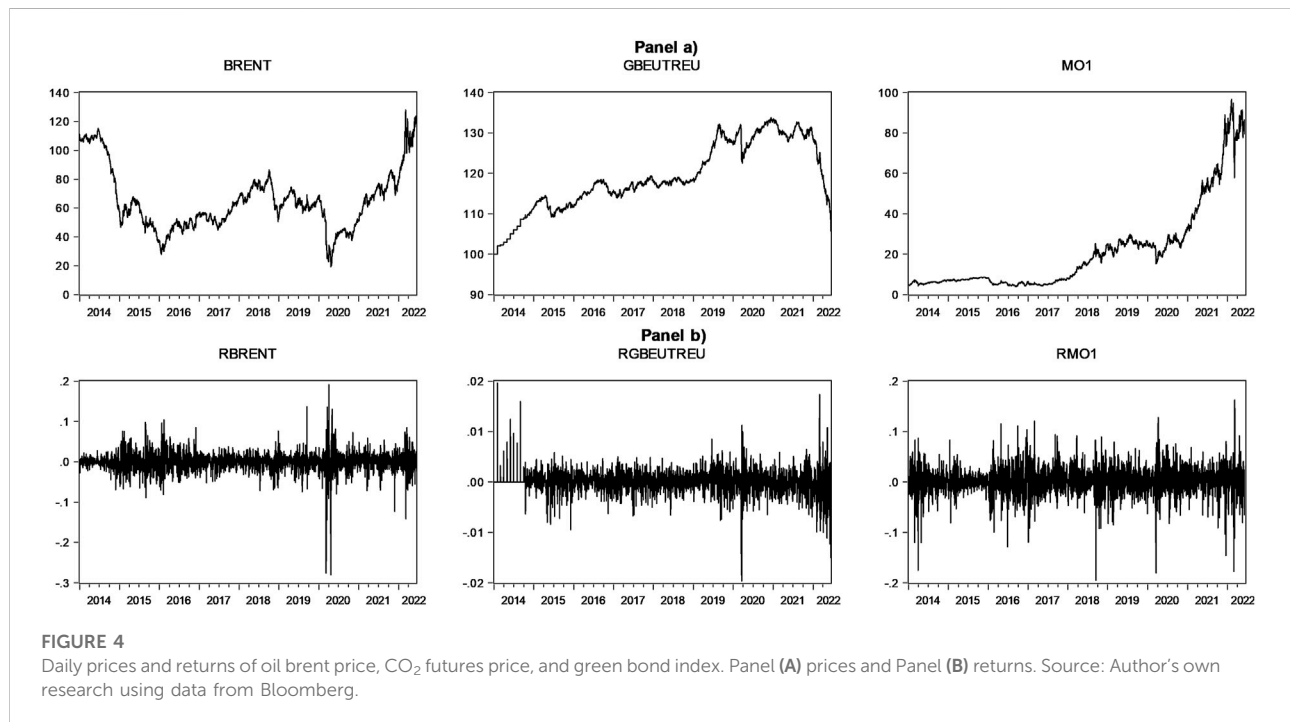
3.1 The dataset

The dataset contains daily closing prices from 1 January 2014 to 15 June 2022 generating 2,206 observations. The variables used in this study are CO₂ emissions, green bond, and brent oil price, as shown in Table 1. The data obtained from the variables are organized in series, then they are transformed to log-returns, yielding 2,206 daily return observations for each variable. All the variables were gathered from Bloomberg.

TABLE 1 List of variables.

Variable	Ticker	Description
CO ₂ futures price	MO1 Comdty	CO ₂ futures price, Euros per ton
Green Bond Index	GBEUTREU Index	Bloomberg MSCI Euro Green Bond Index Total Return Index Value Unhedged
Oil Brent price	CO1 Comdty	Generic 1st Crude Oil, Brent

Source: Authors' own research using Bloomberg.



The MO1 Comdty variable is CO₂ futures' price and indicates Euros per emission ton allowance (European Union Allowances -EUA-) in the Intercontinental Exchange Group (ICE) Europe's futures. The EUA are climate credits (or carbon credits) used in the European Union (EU) Emissions Trading System (ETS). EUA futures Contracts, traded on the ICE, are contracts in which the traders are obliged to make or take the delivery of 1,000 emission allowances. Each allowance is an entitlement to emit one ton of carbon dioxide-equivalent gas (Choi et al., 2020). On the other hand, the Bloomberg MSCI Green Bond Index (GBEUTREU Index) is a Euro fixed income benchmark to fund projects with direct environmental benefits. The index includes Euro-denominated fixed-income securities, including treasury, corporate, government-related, and securitized debt. Securities in the index must be rated Investment Grade (Baa3/BBB-/BBB-) with a minimum size of EUR 300 m. Bonds are evaluated to ensure they adhere to the established Green Bond Principles and can be categorized as green bonds for their environmental use of proceeds.

Additionally, the index offers investors an objective and robust measurement of the market for fixed income securities issued in Euro to fund projects with direct environmental benefits (Bloomberg and MSCI, 2021). On the other hand, the Brent oil price (CO1 Comdty) is included as a fundamental component of energy prices (the energy prices include coal and natural gas). The inclusion of the oil price as a representative energy price is essential because industrial production involves a high fossil fuel consumption. Then, production is an important source of CO₂ emissions, and for this reason, oil prices are determining and driving carbon dioxide prices (Marimoutou and Soury, 2015).

The selected variables are relevant because oil still retains great prominence within the finance world as an essential input for production, a relevant commodity within global financial markets, and a significant source of CO₂ emissions. The considered variables can reflect the recent evolution of the CO₂ emissions and the efforts of green bond markets to contribute toward climate change remediation, conservation of

natural resources, biodiversity enhancement or conservation, pollution control, and prevention (Yan et al., 2022).

Figure 4 shows the evolution of the daily prices and returns of the variables considered in the analysis. The highest peak was observed when the global pandemic started in March 2020. For oil prices, the main shocks are presented in 2014, when the Fed's taper announcement occurred, which caused the fall of financial asset prices, an increase in price volatility, a decline in trade volumes and market liquidity, as well as a rise in government debt which spreaded between the end of May and August 2014 and denoted a market turbulence. It can also be observed that an oil price crisis surged in 2014.

Furthermore, in 2016, it can be noted that the oil price was affected by the protectionist uncertainty for the emerging Latin American markets, especially Mexico. It was due to strong financial and trade relationships with the rest of the world, particularly the United States. Such uncertainty began with the presidential campaign in the United States when the financial markets reflected the nervousness in every presidential debate (Pham et al., 2018). For example, when investors thought that Mr. Trump would win, the market fell, and when it looked more likely that Mrs. Clinton would win, the markets rose. In 2018, the market moved from an oil shortage in the middle of the year to a crude oversupply at the end of the year, which considerably affected the price, as shown in Figure 4. Finally, when the global pandemic produced by coronavirus started in December 2019, the oil price had an important negative impact when world's production presented a significant decrease in the demand for many industrial and technological products. In the first half of 2022, a barrel of oil has presented higher prices due to Russia's invading Ukraine.

Concerning green bonds, this financial mechanism has been attracting an important degree of interest across investors worldwide as an alternative source to finance low-carbon investments. The market for green bonds has grown sharply, from U.S.\$ 3.4 billion in 2012 to US \$156 billion in 2017 (Azhgaliyeva et al., 2020). The issuances practically doubled each year after 2016, and the portion of corporate green bonds has been constantly growing, but the green bond market remains smaller than the conventional bond market (Piñeiro-Chousa et al., 2022). In the Latin American and the Caribbean market, from 2014 to 2020, the issuances of green bonds have had an average annual increase of 1.88x (Mejia-Escobar et al., 2021). It shows an accelerated growth with strong perceptions for investors and issuers to help reach the Sustainable Developments Goals (SDGs). Finally, the price of CO₂ emissions is important because it is related to oil prices. This is one of the leading industrial activities responsible for CO₂ emissions and is also connected to the green bond markets. After all, these markets seek to reduce CO₂ emissions and promote economic activities that are eco-friendly and sustainable in the long term. In Figure 4, it

can be observed how the CO₂ emissions futures' price had increased too, especially after 2018. In 2018, the EU strengthened the ETS cap in order to deliver the 40% emission reduction target by 2030. In 2019, this reform was effective when the Market Stability Reserve (MSR) started operating; It targets an increasingly reduced volume of authorized permits based on the implementation of a rule-based supply-side control, and whose effects were finally reflected on the prices of CO₂ emissions (Osorio et al., 2021).

Table 2 provides the summary statistics of daily returns of the considered series. The daily returns are asymmetric and negatively skewed. It indicates that negative values are predominant in the analyzed period. Hence, this is consistent with leptokurtic and heavy-tailed distortions. In all cases, based on the Jarque-Bera test, the null hypothesis that the distribution is Gaussian is rejected. Also, evidence from the Augmented Dickey-Fuller (ADF) testing for the presence of a root unit in the original time series of the prices is not rejected. It indicates that the original series does not have a constant mean or variance consistent with the series in the financial markets. However, the ADF Test points out the stationarity of all return series (Dickey and Fuller, 1979). Conditional heteroscedasticity is significant, as indicated by the results of the ARCH-LM Test, implying the autocorrelation of the analyzed return series.

On the other hand, pairwise correlations across the returns of the variables considered are presented in Table 3. The correlation of oil price return (RBRENT) with the CO₂ futures' returns (RMO1) is positive (19.81%), and with the Green Bond Index (GBEUTREU) is negative (-5.15%). According to Fatica and Panzica (2021), the issuance of a green bond is associated with a reduction in CO₂ emissions. Finally, the correlation between the CO₂ futures' returns and the Green Bond Index return is negative too (-7.44%). It is expected that CO₂ futures' returns, and oil returns have the same behavior against the Green Bond Index because if oil prices rise, then the CO₂ emissions will increase too (Sadorsky, 2009; Mahmood and Furqan, 2021; Zheng et al., 2021; Mahmood et al., 2022). For example, Zheng et al. (2021) argued that oil shocks might significantly influence emissions, and oil supply can also impact carbon allowance prices. Then, the important role of oil supply and prices in determining emissions and carbon allowance prices appear as a clear pathway and policy framework for countries to regulate and control their emissions and the oil market. Furthermore, they reveal the necessity of including their supply of oil and prices to meet their long-term environmental targets. Then, this phenomenon could lead to more green bond issuances. Thus, the green bonds market correlates more with corporate and treasury bond markets and less with stock and energy commodity markets. In a deeper analysis (Reboredo, 2018), found that green bonds are strongly connected to treasury bonds and corporate bonds in the short- and long-term run and are weakly connected to high-yield corporate bonds, stocks, and energy assets.

TABLE 2 Summary statistics of daily returns.

Index	Mean	Max	Min	Std. Dev	Skewness	Kurtosis	Jarque-bera	ADF	ARCH
RMO1	0.00130	0.16204	-0.19444	0.02922	-0.54243	7.77620	2204.988***	-49.47***	30.48***
RGBEUTREU	0.00003	0.01961	-0.01964	0.00245	-0.34554	12.53055	8392.823***	-43.05***	50.99***
RBRENT	0.00003	0.19077	-0.27976	0.02543	-0.97763	20.42174	28249.69***	-46.36***	30.81***

Notes: This table presents summary statistics of daily returns oil Brent price, CO₂ futures price, and green bond index. The 1 January 2014–15 June 2022 sample yielded 2,206 observations. *** indicates the rejection of the null for both normality test (via Jarque-Bera) and unit root test [via Augmented Dickey-Fuller (ADF)]. The ADF, test is conducted with an intercept; ARCH-LM, is the heteroscedasticity test up to 18 lags. Source: Authors' own research using data from Bloomberg.

TABLE 3 Unconditional correlation of daily returns.

	RMO1	RGBEUTREU	RBRENT
RMO1	1		
RGBEUTREU	-0.0744	1	
RBRENT	0.1981	-0.0515	1

Source: Authors' own research using data from Bloomberg.

3.2 The Granger causality Test

Based on a test, Granger (1969) proposed the notion of causality centered on the asymmetry of the correlation schemes. The test is proposed for a strictly stationary bivariate process $\{(X_t, Y_t)\}$, such that $\{X_t\}$ is a Granger cause of $\{Y_t\}$ if current and past values of X contain extra information on future values of Y that is not contained in current and past Y-values themselves. This definition has key features such as the following.

- X_t and Y_t are stochastic variables.
- The notion of statistical causality, that is, of temporal precedence, is not a substitute for causality in econometric analyses since such statistical causality requires that changes in X_t precede changes in Y_t and that changes in X_t explain or generate Y_t changes.
- The Granger Causality Tests only allow direct causality to be accepted or rejected, but not the existence of indirect causality due to the omission of other variables.

Considering these conditions, Granger (1969) presented the model as follows, with X_t and Y_t as stationary time series with zero mean.

$$\begin{aligned}
 X_t &= \sum_{j=1}^m a_j X_{t-j} + \sum_{j=1}^m b_j Y_{t-j} + \varepsilon_t \\
 Y_t &= \sum_{j=1}^m c_j X_{t-j} + \sum_{j=1}^m d_j Y_{t-j} + \eta_t
 \end{aligned}
 \tag{1}$$

Therefore, ε_t and η_t are uncorrelated white noise series. Mathematically, this equation allows for $m \rightarrow \infty$. However,

empirically the data horizon is finite for m . Furthermore, the causal relationship in this model could be defined as Y_t , causing X_t given $b_j \neq 0$, or X_t causing Y_t given $c_j \neq 0$.

An approximation to instantaneous causality would be the following.

$$\begin{aligned}
 X_t + b_0 Y_t &= \sum_{j=1}^m a_j X_{t-j} + \sum_{j=1}^m b_j Y_{t-j} + \varepsilon_t \\
 Y_t + c_0 X_t &= \sum_{j=1}^m c_j X_{t-j} + \sum_{j=1}^m d_j Y_{t-j} + \eta_t
 \end{aligned}
 \tag{2}$$

This methodology test allows to complement the DCC-Garch Model because it determines the existence of a strong short-term correlation among the variables analyzed. In addition, the existence of unidirectional causality in the sense of Granger (1969) allows to conclude the direction in correlation between a pair of assets.

The Granger Causality Test is carried out as a previous step to the execution of the DCC-Garch Model since. If the test accepts the null hypothesis in both cases, Ho: X does not Granger Cause Y and Ho: Y does not Granger Cause X, then there will not be a relationship between the pair of variables analyzed over time; this would make it ineffective to apply the DCC-Garch Model. However, the DCC-Garch Model can be applied directly to rule out the existence of a co-movement between the pair of variables.

Understanding the generated statistical causal relationship among the analyzed variables has been important since this finding gives greater robustness to the estimated conditional dynamic correlation. Thus, identifying which variable causes the other allows greater clarity on the association's structure among the variables analyzed. Several studies have explored the relationship between the oil price and different variables and the impact of such relationships on the economic results (Behmiri and Pires Manso, 2012; Reboredo, 2018; Troster et al., 2018; Pirgaip and Dincergok, 2020; Bayar et al., 2021). They found empirical evidence of causality relationships running from crude oil price to crude oil consumption and GDP and a bidirectional causality relationship between crude oil consumption and GDP, both in the short and long runs. These results indicate that crude oil conservation policies affect the

OECD economic growth in the short and long runs in the OECD countries. Therefore, policy-makers should consider that increasing crude oil prices or diminishing crude oil consumption negatively impacts on the economic growth rate (Reboredo, 2018).

On the other hand, Troster et al. (2018) collected evidence on bi-directional causality between changes in renewable energy consumption and economic growth at the lowest tail of the distribution and unidirectional causality from fluctuations in oil prices to economic growth at the extreme quantiles of the distribution. Finally, the same authors found evidence of lower-tail dependence from changes in oil prices to changes in renewable energy consumption. These findings call for government policies aimed at developing renewable energy markets to increase energy efficiency. According to Pirgaip and Dincergok (2020), there is a unidirectional causality running from EPU (Economic Policy Uncertainty) to energy consumption in Japan, from EPU to CO₂ emissions in the United States and Germany; and from EPU to both energy consumption and CO₂ emissions in Canada. In Italy, the causality runs from CO₂ emissions to EPU, but a bidirectional causality exists between EPU and energy consumption. The same authors also explored a unidirectional causality from energy consumption to CO₂ in the United States. Based on the findings (Pirgaip and Dincergok, 2020), strongly recommend that the G7 countries consider the possible negative effects of EPU on energy conservation policies, which should be implemented to reduce energy consumption and CO₂ emissions, as committed in the recent climate mandate.

Finally, according to Bayar et al. (2021), the causality analysis revealed a unilateral causality from trade globalization to renewable energy in Estonia, Latvia, and Slovenia. Also, they found another causality from renewable energy to trade globalization in Croatia and Lithuania. However, no significant causality between financial globalization and renewable energy was discovered. On the other hand, a unilateral causality from CO₂ emissions to renewable energy in Lithuania and Slovenia was identified. This can be added to the one evidenced by renewable energy to CO₂ emissions in Czechia, Hungary, and Latvia. It is also relevant to mention the reciprocal causality between, renewable energy to CO₂ emissions in Romania and Slovakia, and a unilateral causality from real GDP per capita to renewable energy in Czechia, Romania, and Slovenia observed in the causality analysis.

3.3 Dynamic conditional correlation model (DCC-Garch)

There is a set of models designed for time-varying correlation based on historical data. The Dynamic Conditional Correlation Model (DCC-Garch) was introduced by Engle (2002), and more recently, it has been related to the ample literature on

multivariate Garch; a series of studies conducted have introduced different methods to estimate conditional correlations (Cappiello et al., 2006; Cappiello et al., 2006b; Bali and Engle, 2010; Colacito et al., 2011; Rangel and Engle, 2012; Engle et al., 2019; Pakel et al., 2021; de Nard et al., 2022). Most of the models implemented by these studies seek to parametrize the covariance matrix of a set of random variables, conditioned to a set of observable state variables that typically include the past realization of the variables of interest (in this case, returns). In this study, The Granger Causality Test has been used to identify causality among the selected variables: green bonds, CO₂ emissions, and oil prices. This test verifies if one variable can predict another variable and if it has a unidirectional or bidirectional character, thus determining the co-movement's direction. Then, the test allows to complement the DCC-Garch Model to conclude if there is a strong correlation between the variables analyzed in the present study.

The test consists of checking if a variable's results are useful to predict another variable, if it has a unidirectional or bidirectional character.

Let $r_{i,t}$ denote the return of asset i at time t , and follows the process (for $i = 1, \dots, n$, $t = 1, \dots, T$).

$$r_{i,t} = \mu_{i,t} + \sigma_{i,t} z_{i,t} \quad (3)$$

where $z_{i,t}$ is a standard normal random variable, $\sigma_{i,t}^2$ and $\mu_{i,t}$ are the conditional variance and mean of the return, respectively. And $\varepsilon_{i,t}$ is the return innovation. Covariances between assets i and j , follow a first order scalar MGARCH (Engle and Kroner, 1995; Engle, 2002; Tse and Tsui, 2002). Then, the specification of the conditional variance is:

$$\sigma_{i,j,t}^2 = \lambda_{i,j} + \alpha \varepsilon_{i,t-1} \varepsilon_{j,t-1} + \beta_j \sigma_{i,t-j}^2 \quad (4)$$

The DCC-Garch Model is characterized by showing if the number of parameters is independent from the number of the used series. Then, Engle (2002) proposes the following process for the MGARCH estimation:

$$W_t = D_t M_t D_t \quad (5)$$

Where M is a matrix of conditional correlations and D is a diagonal matrix with the following form:

$$D_t = \begin{bmatrix} \sigma_{1,t}^2 & 0 & 0 \\ 0 & \sigma_{2,t}^2 & 0 \\ 0 & 0 & \sigma_{3,t}^2 \end{bmatrix} \quad (6)$$

The equation of the conditional correlation matrix written in deviations from the unconditional long-run correlation means of standardized errors (ζ_t) is:

$$M_t = (1 - \alpha - \beta) \bar{R} + \alpha \zeta_{t-1} \zeta_{t-1}' + \beta M_{t-1} \quad (7)$$

Where \bar{R} is the long-run average correlation. The matrix M_t is guaranteed to be positive definite as long as the initial

TABLE 4 Pairwise granger causality tests Lags:2.

Null Hypothesis	Obs	F-Statistic	Prob.	Null Hypothesis
RBRENT does not Granger Cause RGBEUTREU	2204	0.89168	0.4104	Not Rejected
RGBEUTREU does not Granger Cause RBRENT		4.02322	0.0180	Rejected
RBRENT does not Granger Cause RMO1	2204	5.75145	0.0032	Rejected
RMO1 does not Granger Cause RBRENT		0.75946	0.4680	Not Rejected
RMO1 does not Granger Cause RGBEUTREU	2204	1.17328	0.3095	Not Rejected
RGBEUTREU does not Granger Cause RMO1		3.67727	0.0254	Rejected

Source: Author's own research using data from Bloomberg.

parameters α , β , and $(1 - \alpha - \beta)$ are all positive and if the initial value $M1$ is positive definite. The principle behind the mean-reverting DCC-Garch is that when returns move in the same direction, either moving up or down, the correlation will rise above its average level and remain there for a while. Gradually, this phenomenon will decay, and correlations will come back to their long-run average. The parameters α and β determine the speed of the adjustment and are called the correlation's persistence parameters. α represents the impact of past shocks on a current conditional correlation, and β captures the impact of the past correlations. If $\alpha + \beta = 0$, then the model collapses to one with constant conditional correlation (CCC). When the sum of these two parameters approaches one, the estimated correlations become increasingly dynamic. These two parameters will need to be estimated from the data.

The DCC-Garch has been extensively used to analyze dynamic conditional covariances and correlations across investment instruments (Turhan et al., 2014; Basher and Sadorsky, 2016; Singhal and Ghosh, 2016; Surya and Wibowo, 2018). However, the study conducted by Caporin and McAleer (2013) points out some of the limitations of the DCC-Garch representation for estimating and forecasting time-varying conditional correlations. Among the pointed out issues, there is the lack of a proper discussion on stationarity conditions or asymptotic properties of the estimators in most representations or extensions of DCC-Garch. However, stationarity can be achieved by using returns in the model. As stressed by the study, this criticism does not entirely rule out the possibility of using DCC-Garch as a filter or a diagnostic check that can capture the dynamic conditional correlations. Therefore, the recent criticism does not invalidate this paper's effort to use DCC-Garch to obtain time-varying measures of the interdependence across green bonds, CO₂ emissions, and oil prices. As an illustration, several authors use the DCC methodology to estimate the dynamic relationships between the oil price and different financial assets such as exchange

rates, gold, VIX, bonds, and stock markets, among others (Turhan et al., 2014; Basher and Sadorsky, 2016; Singhal and Ghosh, 2016; Surya and Wibowo, 2018).

4 Empirical results

4.1 Causality among the variables

Before analyzing the DCC-Garch Model, the Granger Causality Test is presented in order to identify the causality among the selected variables with a level of 95% of confidence. As shown in Table 4, results indicate a unidirectional causality from Green Bond Index (RGBEUTREU) to oil price returns (RBRENT) due to the not rejection of the null hypothesis. This research results suggest that environmental investments affect oil prices. It means that the movements in green bond prices lead to changes in oil prices. In contrast, Lee et al. (2021) found a bi-directional lower-tail causality between crude oil and green bond markets, which indicates a feedback relationship, suggesting that oil prices and green bond prices are interdependent when these markets are in a bearish state (lower quantile).

Also, a unidirectional causality runs from oil price returns (RBRENT) to CO₂ futures' returns (RMO1) as a result of the not rejection of the null hypothesis. In this case, there is evidence that oil prices directly impact the future prices of CO₂ emissions. In the same line, Mensah et al. (2019) determined a unilateral cause from oil prices to carbon emissions both in the long and short run. According to the results, a unidirectional causality runs from the Green Bond Index (RGBEUTREU) to the CO₂ futures' returns (RMO1) indicate by the not rejection of the null hypothesis. It means that green bonds have a unidirectional connection with the CO₂ futures' returns. Then, if the strong demand for the green bond market occurs, in turn, it will affect the CO₂ permits. This result is supported by Hung (2021). Nevertheless, Hammoudeh et al. (2020) indicate that the Green Bond

Index does not cause the CO₂ futures' returns and observed a significant causality from CO₂ futures' returns to green bonds, especially in 2015, when oil prices collapsed.

4.2 Dynamic conditional correlations among the variables

Table 5 shows the DCC-Garch parameters estimates from the pairwise considered, which are significantly different from zero. The estimated parameters α and β in the DCC-Garch Models capture the effects of lagged standardized shocks and lagged conditional correlations. When α increases, the lagged squared residuals (the ARCH terms) play an increasingly important role in estimating the correlation. If β increases, the conditional correlation becomes more persistent.

In most of the DCC-Garch Models' results, the magnitude of β indicates a strong persistence in the dynamic conditional correlation, except for the relationship among the CO₂ futures' returns and the Green Bond Index ρ (RMO1, RGBEUTREU), which present a moderate value of β (0.448). Additionally, the sum of the conditional correlations also exhibited high persistence ($\alpha + \beta$), with the average sum of the two coefficients being over 0.678 during the sample period. Then, the estimated correlations become increasingly dynamic. This implies that the analyzed pairs' volatility process is stable

and presents a high degree of persistence concerning the past correlations. Parameter β captures the high impact of the past correlations in all the cases. The results showed a low impact of the innovations, measured by α . Then, there is a lower variance in the correlation process.

Figure 5 presents a common characteristic of pairwise correlations shown: they reached two peaks. The first peak was during the beginning of the global pandemic in 2019–2020, and the second peak in 2022, which resulted from Russia's invasion to Ukraine. Then, the peaks of the conditional correlations coincided with these two major events that affected almost all the variables in the economies.

The DCC-Garch Model reveals a time-varying correlation in the range of $[-0.33; 0.55]$ between oil and CO₂ futures' returns $[-0.37; 0.26]$ between oil and the Green Bond Index, and $[-0.69; 0.088]$ between the Green Bond Index and the CO₂ futures' returns (Figure 5 and Table 6). The results are consistent with Chevallier (2012), who found a dynamic correlation of $[-0.05; 0.05]$ between oil and the CO₂ futures' prices of the European Climate Exchange (ECX) using data from 2005 to 2008. Additionally, several studies have confirmed the existence of a positive correlation and considerable co-movements between CO₂ emissions and oil prices (Boersen and Scholtens, 2014; Koch, 2014; Chang et al., 2019; Chen et al., 2019; Lee and Yoon, 2020).

The oil price is connected to the demand of green markets because lower oil prices induce oil demand and may alter the demand for socially responsible investment (Sadorsky, 2014; Broadstock and Cheng, 2019). Then a negative correlation is expected between these two variables. In this way, Sadorsky (2014) using weekly data from 1998 to 2012, a dynamic correlation of $[-0.37; 0.58]$ between oil and Socially Responsible Investing (SRI) was found, which refers to investing in companies that score well on environmental, social, and governance (ESG) factors. This variable can be used as a proxy for green markets. In contrast, Syed et al. (2022) employing the Nonlinear

TABLE 5 Estimated parameters of DCC-Garch models.

Pair	Alpha (α)	Beta (β)	(α) + (β)
ρ (RBRENT, RMO1)	0.064***	0.654***	0.718
ρ (RBRENT, RGBEUTREU)	0.039***	0.760***	0.799
ρ (RMO1, RGBEUTREU)	0.069***	0.448***	0.518

Source: Authors' own research using data from Bloomberg. Notes: *, **, and *** indicate a significance at the 10, 5 and 1% level, respectively.

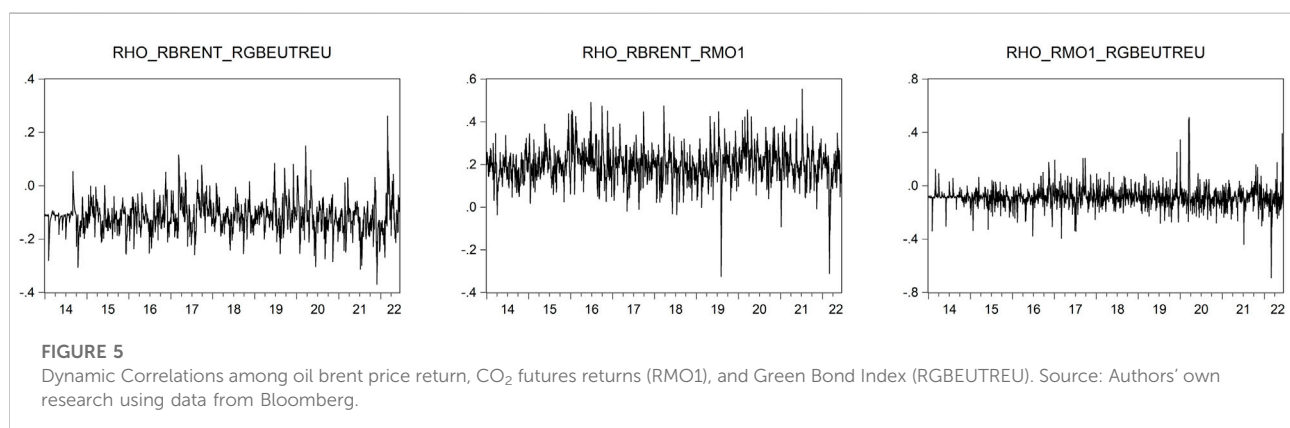


TABLE 6 Descriptive statistics of rho (ρ) coefficients obtained from DCC-Garch models.

Pair	Mean	Max	Min	Std. Dev	Skewness	Kurtosis	Jarque-bera	ADF	ARCH
ρ (RBRENT, RMO1)	0.198	0.552	-0.325	0.077	-0.21	6.54	1171.2***	2486.9***	-18.46***
ρ (RBRENT, RGBEUTREU)	-0.115	0.261	-0.370	0.056	0.46	5.93	863.7***	4119.5***	-15.16***
ρ (RMO1, RGBEUTREU)	-0.088	0.513	-0.692	0.070	0.92	17.60	19,902.9***	1078.6***	-24.48***

Notes: This table presents summary statistics of daily returns oil brent price, CO₂ futures price, and green bond index. The 1 January 2014–15 June 2022 sample yielded 2,206 observations. *** indicates the rejection of the null for both normality test (via Jarque-Bera) and unit root test [via Augmented Dickey-Fuller (ADF)]. The ADF, test is conducted with an intercept; ARCH-LM, is the heteroscedasticity test up to 18 lags. Source: Author's own research using data from Bloomberg.

TABLE 7 Month-wise DCC-Garch results.

Pairs/Time	ρ (RBRENT, RMO1)	ρ (RBRENT, RGBEUTREU)	ρ (RMO1, RGBEUTREU)
Panel A: COVID-19			
January-20	0.21231	-0.08804	-0.07001
February-20	0.29864	-0.12295	-0.10296
March-20	0.28042	-0.04599	0.03745
April-20	0.23782	-0.11430	-0.11155
May-20	0.19720	-0.07983	-0.10051
June-20	0.23108	-0.17117	-0.07870
July-20	0.18393	-0.10065	-0.12284
August-20	0.24349	-0.11337	-0.07244
September-20	0.18970	-0.15574	-0.09765
October-20	0.19658	-0.10723	-0.09595
November-20	0.24697	-0.14450	-0.09766
December-20	0.20592	-0.13270	-0.11251
Panel B: Russian invasion of Ukraine			
January-22	0.22372	-0.16593	-0.09304
February-22	0.16951	-0.13325	-0.11270
March-22	0.04022	0.00522	-0.19210
April-22	0.18745	-0.06192	-0.08072
May-22	0.21730	-0.14930	-0.10828
June-22	0.12983	-0.06950	-0.00481

Source: Authors' own research using data from Bloomberg.

Autoregressive Distribution Lag (NARDL) for studying the dynamic linkage between the oil price and green bonds, concluded that oil prices positively influence the green bonds performance. The study found that a 1 percent increase (decrease) in oil prices increases (decreases) the performance of green bonds by 0.05 percent.

To describe the dynamic correlation between the Green Bond Index (RGBEUTREU) and the CO₂ futures' returns (RMO1), it is necessary to keep in mind that investment in

green projects such as trading green bonds can effectively mitigate the risks of CO₂ emissions (Naeem et al., 2021). However, there is a lack of studies that apply dynamic techniques to the relation between these two variables.

Table 6 describes the statistics of rho (ρ) coefficients obtained from the DCC-Garch Models. The mean value of the DCC coefficient between the Brent oil price return and the CO₂ futures' returns ρ (RBRENT, RMO1) is positive (19,8%). Furthermore, a negative average DCC-Garch coefficient is

shown between the Green Bond Index and the oil price $\rho(\text{RBRENT}, \text{RBEUTREU})$, and the CO₂ futures' returns $\rho(\text{RMO1}, \text{RBEUTREU})$ (−11,5% and −8,8%, respectively). All the DCC rho coefficients present autocorrelation (see ARCH test results), meaning a time dependence structure with its lags. Finally, all rho coefficients are stationary, this implies that correlations found have a constant mean and variance.

4.3 Sensitivity analysis

In this section, we perform a sensitivity analysis of DCC models considering two identified crisis periods in the sample period to compare the results with the complete sample (Prabheesh et al., 2020; Akram and Haider, 2022; Rai and Garg, 2022). Table 7 reports the month-wise coefficient of the dynamic correlation rho (ρ) between oil price returns (RBRENT), the CO₂ futures' returns (RMO1), and the Green Bond Index (RBEUTREU). This analysis is conducted due to our sample period being ideal for testing the impact of two recent events that induced economic crises and influence the dynamic relationship between the analyzed variables. These events are the COVID-19 pandemic (Panel A) and the Russian invasion of Ukraine (Panel B). In Panel A, we find a solid positive dynamic correlation (0.28) between Brent oil price return and the CO₂ futures' returns $\rho(\text{RBRENT}, \text{RMO1})$, especially in March 2020 when the global confinement started. Also, a weak negative dynamic correlation (−0.045) between the Green Bond Index and the oil price $\rho(\text{RBRENT}, \text{RBEUTREU})$. Remarkably, the relationship between CO₂ futures' returns and the Green Bond Index became positive (0.037) in March 2020 $\rho(\text{RMO1}, \text{RBEUTREU})$. The results imply that the uncertainty revolving around the COVID-19 outbreak led to a change in the dynamics between the variables. For instance, the oil demand decreased, and oil prices decline around the world. Further, the global production fall induced the reduction of CO₂ emissions and Green Bond have a small increment of the issuances in 2020 compared to 2019.

In Panel B, the results caused by the Russian invasion of Ukraine in February and the consequent European energy crisis exacerbated post-COVID-19 inflation impacting the dynamic correlation between the variables considered. The results are opposite to the findings of the global pandemic, especially in March 2022. We find a weak positive dynamic correlation (0.040) between Brent oil price return and the CO₂ futures' returns $\rho(\text{RBRENT}, \text{RMO1})$, a lack of correlation (0.005) between the Green Bond Index and the oil price $\rho(\text{RBRENT}, \text{RBEUTREU})$, and finally a solid negative dynamic correlation (−0.192) among the CO₂ futures' returns and the Green Bond Index $\rho(\text{RMO1}, \text{RBEUTREU})$. The macroeconomic context of rising

interest rates, increase in commodity prices including oil prices, and high volatility of the financial markets resulted in a decrease in the green bond issuance and uncertainty in the CO₂ futures' returns (Figure 4, Panel A). Our findings are in agreement with Baur (2012), who suggests that a crisis period led to an increased co-movement of returns among financial markets, and Gajurel and Chawla (2022) who argue the majority of the economic sectors experience the contagion effect from the global oil market during the crisis period.

5 Concluding remarks and policy implications

This study explores the dynamic relationship among green bonds, CO₂ emissions, and oil prices. Oil is a significant determinant of global economic performance, and its price's dynamics can affect the world's economy in several ways, such as the market assets and the economic production. An increase in the oil prices will raise the cost of production of goods and services, leading to a rise in price levels and high inflation. Concerns about possible increases in price levels will produce uncertainty and negative sentiments in the financial markets, and the expected inflation will lower equity values. In addition, oil prices can set economic trends by driving the gross domestic product's growth (GDP). Hence, there is evidence of a linkage among the three variables analyzed: green bonds, CO₂ emissions, and oil price; it is due to the existing connection among them in industrial production (Figure 1), then the three represent the development of the economic activity in the present.

Understanding the interactions and dynamic relationships between green bonds, CO₂ emissions, and oil prices are paramount to ethical investors. This information is essential for gaining superior risk-adjusted returns through properly allocating a sustainable financial portfolio and managing risk (Dutta et al., 2021). The results for the negative co-movements between green bonds with the oil prices and among green bonds with CO₂ futures' price have two major implications. The first is that negative correlations provide diversification opportunities for investors worldwide. The second concerns policy-makers; when oil prices and CO₂ futures' price increase, the Green Bonds Index is expected to decrease. Then green bonds appear as an attractive financial mechanism for environmentally friendly investors; issuers can employ this device to diversify their investor base and improve their environmental, social, and governance (ESG) scores (Reboredo and Ugolini, 2020; Dutta et al., 2021). These results appear as an opportunity for policy-makers to design strategies for promoting eco-friendly policies that contribute to enlarging the supply of green bonds,

allowing sustainable investment portfolios to be structured. Finally, the relation between the CO₂ futures' price and the oil price is mostly positive, which is helpful for forecasting the CO₂ futures' price according to the evolution of the oil price in the international markets.

Despite the contributions of the present study, limitations should be acknowledged. First, the daily data are available only for developed markets such as Europe. This is mainly due to the lack of data for dynamic correlation studies among CO₂ emissions and green bond markets to contrast the results obtained in this analysis, for example, data from the emerging markets. Second, the limited literature on green bond markets and their relations with oil prices and CO₂ emissions simultaneously to compare results.

The above findings are relevant to investors and policy-makers keen to understand the dynamics of conditional correlations among green bonds, CO₂ prices, and oil prices, which can affect diversification strategies and the design of environmental policies. In this regard, given that green bonds are becoming an essential financial mechanism for achieving the SDGs, it is also mandatory to gain a better understanding of decision-makers perspectives in designing investment portfolios. Further research could also help to comprehend this issue deeply in this concern. Thus, there is great potential for further research on green bonds and their relationships with other financial assets, particularly those highly related to investment decisions, for example, stocks, which have been little explored. For this, machine learning models could be implemented. These studies could also be extended to Latin American and the Caribbean markets, where research on these issues is scarce. Furthermore, a hedging analysis can be conducted in further research of co-movements, their time-frequency domains, and investment horizons can have implications for dynamic hedging, asset allocation, and utility earnings. Finally, the authors hope that finance will be fully sustainable in the short term. In this scenario, green bond will be a pivotal player.

References

- Adom, P. K., Kwakwa, P. A., and Amankvaa, A. (2018a). The long-run effects of economic, demographic, and political indices on actual and potential CO₂ emissions. *J. Environ. Manag.* 218, 516–526. doi:10.1016/j.jenvman.2018.04.090
- Adom, P. K., Kwakwa, P. A., and Amankvaa, A. (2018b). The long-run effects of economic, demographic, and political indices on actual and potential CO₂ emissions. *J. Environ. Manag.* 218, 516–526. doi:10.1016/j.jenvman.2018.04.090
- Akca, H. (2021). Environmental Kuznets curve and financial development in Turkey: Evidence from augmented ARDL approach. *Environ. Sci. Pollut. Res.* 28, 69149–69159. doi:10.1007/s11356-021-15417-w
- Akkoc, U., and Civcir, I. (2019). Dynamic linkages between strategic commodities and stock market in Turkey: Evidence from SVAR-DCC-GARCH model. *Resour. Policy* 62, 231–239. doi:10.1016/j.resourpol.2019.03.017
- Akram, V., and Haider, S. (2022). A dynamic nexus between COVID-19 sentiment, clean energy stocks, technology stocks, and oil prices: Global evidence. *Energy Res. Lett.* 3, 32625. doi:10.46557/001c.32625
- Alshehry, A. S., and Belloumi, M. (2017). Study of the environmental Kuznets curve for transport carbon dioxide emissions in Saudi Arabia. *Renew. Sustain. Energy Rev.* 75, 1339–1347. doi:10.1016/j.rser.2016.11.122
- Aria, M., and Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *J. Inf.* 11, 959–975. doi:10.1016/j.joi.2017.08.007
- Azhgaliyeva, D., Kapoor, A., and Liu, Y. (2020). Green bonds for financing renewable energy and energy efficiency in south-east asia: A review of policies. *J. Sustain. Finance Invest.* 10, 113–140. doi:10.1080/20430795.2019.1704160
- Azhgaliyeva, D., Kapsalyamova, Z., and Mishra, R. (2022). Oil price shocks and green bonds: An empirical evidence. *Energy Econ.* 112, 106108. doi:10.1016/j.eneco.2022.106108

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Materials, further inquiries can be directed to the corresponding author.

Author contributions

NM-R: Writing, conceptualization, methodology, data collection, empirical analysis, writing original draft. JG-R: Conceptualization, writing, review, editing, and supervision. SB: Conceptualization—review, editing, and supervision. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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- Azhgaliyeva, D., Mishra, R., and Kapsalyamova, Z. (2021). *Oil price shocks and green bonds: A longitudinal multilevel model*. Tokyo: Asian Development Bank. Available at: <https://www.adb.org/publications/oil-price-shocks-green-bonds-longitudinal-multilevel-model> (Accessed May 15, 2022).
- Balaguer, J., and Cantavella, M. (2016). Estimating the environmental Kuznets curve for Spain by considering fuel oil prices (1874–2011). *Ecol. Indic.* 60, 853–859. doi:10.1016/j.ecolind.2015.08.006
- Bali, T. G., and Engle, R. F. (2010). The intertemporal capital asset pricing model with dynamic conditional correlations. *J. Monetary Econ.* 57, 377–390. doi:10.1016/j.jmoneco.2010.03.002
- Basher, S. A., and Sadorsky, P. (2016). Hedging emerging market stock prices with oil, gold, VIX, and bonds: A comparison between DCC, adcc and GO-GARCH. *Energy Econ.* 54, 235–247. doi:10.1016/j.eneco.2015.11.022
- Baur, D. G. (2012). Financial contagion and the real economy. *J. Bank. Finance* 36, 2680–2692. doi:10.1016/j.jbankfin.2011.05.019
- Bayar, Y., Sasmaz, M. U., and Ozkaya, M. H. (2021). Impact of trade and financial globalization on renewable energy in EU transition economies: A bootstrap panel granger causality test. *Energies (Basel)* 14, 19. doi:10.3390/en1410019
- Behmiri, N. B., and Pires Manso, J. R. (2012). Crude oil conservation policy hypothesis in OECD (organisation for economic cooperation and development) countries: A multivariate panel granger causality test. *Energy* 43, 253–260. doi:10.1016/j.energy.2012.04.032
- Bloomberg, and MSCI (2021). Bloomberg MSCI Green Bond Indices. Bringing clarity to the green bond market through benchmark indices. Available at: <https://www.msci.com/documents/1296102/26180598/BBG+MSCI+Green+Bond+Indices+Primer.pdf> (Accessed June 9, 2022).
- Boersen, A., and Scholtens, B. (2014). The relationship between European electricity markets and emission allowance futures prices in phase II of the EU (European Union) emission trading scheme. *ENERGY* 74, 585–594. doi:10.1016/j.energy.2014.07.024
- Boufateh, T. (2019). The environmental Kuznets curve by considering asymmetric oil price shocks: Evidence from the top two. *Environ. Sci. Pollut. Res.* 26, 706–720. doi:10.1007/s11356-018-3641-3
- Broadstock, D. C., and Cheng, L. T. W. (2019). Time-varying relation between black and green bond price benchmarks: Macroeconomic determinants for the first decade. *Finance Res. Lett.* 29, 17–22. doi:10.1016/j.frl.2019.02.006
- Caporin, M., and McAleer, M. (2013). Ten things you should know about the dynamic conditional correlation representation. *Econometrics* 1, 115–126. doi:10.3390/econometrics101115
- Cappiello, L., Engle, R. F., and Sheppard, K. (2006). Asymmetric dynamics in the correlations of global equity and bond returns. *J. Financial Econ.* 4, 537–572. doi:10.1093/jfinc/nbl005
- Chang, K., Ye, Z., and Wang, W. (2019). Volatility spillover effect and dynamic correlation between regional emissions allowances and fossil energy markets: New evidence from China's emissions trading scheme pilots. *Energy* 185, 1314–1324. doi:10.1016/j.energy.2019.07.132
- Chen, Q., and Taylor, D. (2020). Economic development and pollution emissions in Singapore: Evidence in support of the Environmental Kuznets Curve hypothesis and its implications for regional sustainability. *J. Clean. Prod.* 243, 118637. doi:10.1016/j.jclepro.2019.118637
- Chen, Y., Qu, F., Li, W., and Chen, M. (2019). Volatility spillover and dynamic correlation between the carbon market and energy markets. *J. Bus. Econ. Manag.* 20, 979–999. doi:10.3846/jbem.2019.10762
- Cherubini, F. (2010). The biorefinery concept: Using biomass instead of oil for producing energy and chemicals. *Energy Convers. Manag.* 51, 1412–1421. doi:10.1016/j.enconman.2010.01.015
- Chevallier, J. (2012). Time-varying correlations in oil, gas and CO2 prices: An application using BEKK, CCC and DCC-MGARCH models. *Appl. Econ.* 44, 4257–4274. doi:10.1080/00036846.2011.589809
- Choi, D., Gao, Z., and Jiang, W. (2020). Attention to global warming. *Rev. Financ. Stud.* 33, 1112–1145. doi:10.1093/rfs/hhz086
- Civcir, İ., and Akkoç, U. (2021). Dynamic volatility linkages and hedging between commodities and sectoral stock returns in Turkey: Evidence from SVAR-cDCC-GARCH model. *Int. J. Fin. Econ.* 26, 1978–1992. doi:10.1002/ijfe.1889
- Colacito, R., Engle, R. F., and Ghysels, E. (2011). A component model for dynamic correlations. *J. Econ.* 164, 45–59. doi:10.1016/j.jeconom.2011.02.013
- de Nard, G., Engle, R. F., Ledoit, O., and Wolf, M. (2022). Large dynamic covariance matrices: Enhancements based on intraday data. *J. Bank. Finance* 138, 106426. doi:10.1016/j.jbankfin.2022.106426
- de Souza, E. S., Freire, F. de S., and Pires, J. (2018). Determinants of CO2 emissions in the MERCOSUR: The role of economic growth, and renewable and non-renewable energy. *Environ. Sci. Pollut. Res.* 25, 20769–20781. doi:10.1007/s11356-018-2231-8
- Dickey, D. A., and Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *J. Am. Stat. Assoc.* 74, 427–431. doi:10.1080/01621459.1979.10482531
- Dutta, A., Bouri, E., and Noor, M. H. (2018). Return and volatility linkages between CO2 emission and clean energy stock prices. *Energy* 164, 803–810. doi:10.1016/j.energy.2018.09.055
- Dutta, A., Bouri, E., and Noor, M. H. (2021). Climate bond, stock, gold, and oil markets: Dynamic correlations and hedging analyses during the COVID-19 outbreak. *Resour. Policy* 74, 102265. doi:10.1016/j.resourpol.2021.102265
- Engle, R. (2002). Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroskedasticity models. *J. Bus. Econ. Stat.* 20, 339–350. doi:10.1198/073500102288618487
- Engle, R. F., and Kroner, K. F. (1995). Multivariate simultaneous generalized arch. *Econ. Theory* 11, 122–150. doi:10.1017/S026646660009063
- Engle, R. F., Ledoit, O., and Wolf, M. (2019). Large dynamic covariance matrices. *J. Bus. Econ. Stat.* 37, 363–375. doi:10.1080/07350015.2017.1345683
- Erdogan, S., Okumus, I., and Guzel, A. E. (2020). Revisiting the environmental Kuznets curve hypothesis in OECD countries: The role of renewable, non-renewable energy, and oil prices. *Environ. Sci. Pollut. Res.* 27, 23655–23663. doi:10.1007/s11356-020-08520-x
- Fatica, S., and Panzica, R. (2021). Green bonds as a tool against climate change? *Bus. Strategy Environ.* 30, 2688–2701. doi:10.1002/bse.2771
- Filis, G., Degiannakis, S., and Floros, C. (2011). Dynamic correlation between stock market and oil prices: The case of oil-importing and oil-exporting countries. *Int. Rev. Financial Analysis* 20, 152–164. doi:10.1016/j.irfa.2011.02.014
- Ftiti, Z., Guesmi, K., Teulon, F., and Chouachi, S. (2016). Relationship between crude oil prices and economic growth in selected OPEC countries. *J. Appl. Bus. Res.* 32, 11–22. doi:10.19030/jabr.v32i1.9483
- Gajurel, D., and Chawla, A. (2022). The oil price crisis and contagion effects on the Canadian economy. *Appl. Econ.* 54, 1527–1543. doi:10.1080/00036846.2021.1980196
- González-Ruiz, J. D., Mejía-Escobar, J. C., Rojo-Suárez, J., and Alonso-Conde, A.-B. (2023). Green bonds for renewable energy in Latin America and the Caribbean. *Energy J.* 44. doi:10.5547/01956574.44.4.jgon
- Granger, C. W. J. (1969). Investigating Causal Relations by Econometric Models and Cross-Spectral Methods. *Essays in Econ.* Editors E. Ghysels, N. R. Swanson, and M. W. Watson 2, 31–47. doi:10.1017/CBO9780511753978.002
- Hammoudeh, S., Ajmi, A. N., and Mokni, K. (2020). Relationship between green bonds and financial and environmental variables: A novel time-varying causality. *Energy Econ.* 92, 104941. doi:10.1016/j.eneco.2020.104941
- Henriques, I., and Sadorsky, P. (2008). Oil prices and the stock prices of alternative energy companies. *Energy Econ.* 30, 998–1010. doi:10.1016/j.eneco.2007.11.001
- Hung, N. T. (2021). Nexus between green bonds, financial, and environmental indicators. *Econ. Bus. Lett.* 10, 191–199. doi:10.17811/ebl.10.3.2021.191-199
- Jin, J., Han, L., Wu, L., and Zeng, H. (2020). The hedging effect of green bonds on carbon market risk. *Int. Rev. Financial Analysis* 71, 101509. doi:10.1016/j.irfa.2020.101509
- Khan, I., Rehman, F. U., Pyplacz, P., Khan, M. A., Wisniewska, A., and Liczmanska-Kopcewicz, K. (2021). A dynamic linkage between financial development, energy consumption and economic growth: Evidence from an asymmetric and nonlinear ARDL model. *Energies (Basel)* 14, 5006. doi:10.3390/en14165006
- Koch, N. (2014). Dynamic linkages among carbon, energy and financial markets: A smooth transition approach. *Appl. Econ.* 46, 715–729. doi:10.1080/00036846.2013.854301
- Lamouchi, R. A., and Alawi, S. M. (2020). Dynamic linkages between the oil spot, oil futures, and stock markets: Evidence from Dubai. *Int. J. Energy Econ. Policy* 10, 377–383. doi:10.32479/ijeeep.8705
- Le, T.-H., and Nguyen, C. P. (2019). Is energy security a driver for economic growth? Evidence from a global sample. *Energy Policy* 129, 436–451. doi:10.1016/j.enpol.2019.02.038
- Le, T.-L., Abakah, E. J. A., and Tiwari, A. K. (2021). Time and frequency domain connectedness and spill-over among fintech, green bonds and cryptocurrencies in the age of the fourth industrial revolution. *Technol. Forecast. Soc. Change* 162, 120382. doi:10.1016/j.techfore.2020.120382

- Lee, C.-C., Lee, C.-C., and Li, Y.-Y. (2021). Oil price shocks, geopolitical risks, and green bond market dynamics. *North Am. J. Econ. Finance* 55, 101309. doi:10.1016/j.najef.2020.101309
- Lee, Y., and Yoon, S.-M. (2020). Dynamic spillover and hedging among carbon, biofuel and oil. *Energies (Basel)* 13, 4382. doi:10.3390/en13174382
- Lin, B., and Chen, Y. (2019). Dynamic linkages and spillover effects between cet market, coal market and stock market of new energy companies: A case of beijing cet market in China. *Energy* 172, 1198–1210. doi:10.1016/j.energy.2019.02.029
- Lin, J.-B., and Tsai, W. (2019). The relations of oil price change with fear gauges in global political and economic environment. *Energies (Basel)* 14, 2982. doi:10.3390/en12152982
- Liu, X., Bouri, E., and Jalkh, N. (2021). Dynamics and determinants of market integration of green, clean, dirty energy investments and conventional stock indices. *Front. Environ. Sci.* 9, 786528. doi:10.3389/fenvs.2021.786528
- Ma, Z., Yan, Y., Wu, R., and Li, F. (2021). Research on the correlation between WTI crude oil futures price and European carbon futures price. *Front. Energy Res.* 9, 735665. doi:10.3389/feng.2021.735665
- Mahmood, H., Asadov, A., Tanveer, M., Furqan, M., and Yu, Z. (2022). Impact of oil price, economic growth and urbanization on CO2 emissions in GCC countries: Asymmetry analysis. *Sustainability* 14, 4562. doi:10.3390/su14084562
- Mahmood, H., and Furqan, M. (2021). Oil rents and greenhouse gas emissions: Spatial analysis of gulf cooperation council countries. *Environ. Dev. Sustain.* 23, 6215–6233. doi:10.1007/s10668-020-00869-w
- Malik, M. I., and Rashid, A. (2017). Return and volatility spillover between sectoral stock and oil price: Evidence from Pakistan stock exchange. *Ann. Finan. Econ.* 12, 1750007. doi:10.1142/S2010495217500075
- Marimoutou, V., and Soury, M. (2015). Energy markets and CO2 emissions: Analysis by stochastic copula autoregressive model. *Energy* 88, 417–429. doi:10.1016/j.energy.2015.05.060
- Marquez-Cardenas, V., Gonzalez-Ruiz, J. D., and Duque-Grisales, E. (2021). Board gender diversity and firm performance: Evidence from Latin America. *J. Sustain. Finance Invest.* 12, 785–808. doi:10.1080/20430795.2021.2017256
- Marshall, A. (1890). *Principles of economics, 8th edn (1920)*. London: Mcmillan.
- Mejía-Escobar, J. C., González-Ruiz, J. D., and Duque-Grisales, E. (2020). Sustainable financial products in the Latin America banking industry: Current status and insights. *Sustain. Switz.* 12, 5648. doi:10.3390/su12145648
- Mejía-Escobar, J. C., González-Ruiz, J. D., and Franco-Sepúlveda, G. (2021). Current state and development of green bonds market in the Latin America and the caribbean. *Sustain. Switz.* 13, 10872. doi:10.3390/su131910872
- Melek, N. C. (2018). *The response of US investment to oil price shocks: Does the shale boom matter?* Kansas City: Economic Review, Federal Reserve Bank of Kansas City forthcoming.
- Mensah, I. A., Sun, M., Gao, C., Omari-Sasu, A. Y., Zhu, D., Ampimah, B. C., et al. (2019). Analysis on the nexus of economic growth, fossil fuel energy consumption, CO2 emissions and oil price in Africa based on a PMG panel ARDL approach. *J. Clean. Prod.* 228, 161–174. doi:10.1016/j.jclepro.2019.04.281
- Moomaw, W. R., and Unruh, G. C. (1997). Are environmental Kuznets curves misleading us? The case of CO2 emissions. *Environ. Dev. Econ.* 2, 451–463. doi:10.1017/S1355770X97000247
- Moutinho, V., Madaleno, M., and Elheddad, M. (2020). Determinants of the Environmental Kuznets Curve considering economic activity sector diversification in the OPEC countries. *J. Clean. Prod.* 271, 122642. doi:10.1016/j.jclepro.2020.122642
- Naeem, M. A., Mbarki, I., Alharthi, M., Omri, A., and Shahzad, S. J. H. (2021). Did COVID-19 impact the connectedness between green bonds and other financial markets? Evidence from time-frequency domain with portfolio implications. *Front. Environ. Sci.* 9, 657533. doi:10.3389/fenvs.2021.657533
- Naser, H. (2015). Analysing the long-run relationship among oil market, nuclear energy consumption, and economic growth: An evidence from emerging economies. *ENERGY* 89, 421–434. doi:10.1016/j.energy.2015.05.115
- Nguyen, T. T. H., Naeem, M. A., Balli, F., Balli, H. O., and Vo, X. V. (2021). Time-frequency comovement among green bonds, stocks, commodities, clean energy, and conventional bonds. *Finance Res. Lett.* 40, 101739. doi:10.1016/j.frl.2020.101739
- Omri, A., ben Mabrouk, N., and Sassi-Tmar, A. (2015a). Modeling the causal linkages between nuclear energy, renewable energy and economic growth in developed and developing countries. *Renew. Sustain. Energy Rev.* 42, 1012–1022. doi:10.1016/j.rser.2014.10.046
- Omri, A., Daly, S., and Nguyen, D. K. (2015b). A robust analysis of the relationship between renewable energy consumption and its main drivers. *Appl. Econ.* 47, 2913–2923. doi:10.1080/00036846.2015.1011312
- Osorio, S., Tietjen, O., Pahle, M., Pietzcker, R. C., and Edenhofer, O. (2021). Reviewing the Market Stability Reserve in light of more ambitious EU ETS emission targets. *Energy Policy* 158, 112530. doi:10.1016/j.enpol.2021.112530
- Pakel, C., Shephard, N., Sheppard, K., and Engle, R. F. (2021). Fitting vast dimensional time-varying covariance models. *J. Bus. Econ. Stat.* 39, 652–668. doi:10.1080/07350015.2020.1713795
- Pata, U. K. (2021). Linking renewable energy, globalization, agriculture, CO2 emissions and ecological footprint in bric countries: A sustainability perspective. *Renew. energy* 173, 197–208. doi:10.1016/j.renene.2021.03.125
- Pham, H. N. A., Ramiah, V., Moosa, N., Huynh, T., and Pham, N. (2018). The financial effects of Trumpism. *Econ. Model.* 74, 264–274. doi:10.1016/j.econmod.2018.05.020
- Piñeiro-Chousa, J., López-Cabarcos, M. Á., and Šević, A. (2022). Green bond market and Sentiment: Is there a switching Behaviour? *J. Bus. Res.* 141, 520–527. doi:10.1016/j.jbusres.2021.11.048
- Pirgaip, B., and Dincergok, B. (2020). Economic policy uncertainty, energy consumption and carbon emissions in G7 countries: Evidence from a panel granger causality analysis. *Environ. Sci. Pollut. Res.* 27, 30050–30066. doi:10.1007/s11356-020-08642-2
- Prabheesh, K. P., Padhan, R., and Garg, B. (2020). COVID-19 and the oil price – stock market nexus: Evidence from net oil-importing countries. *Energy Res. Lett.* 1, 13745. doi:10.46557/001c.13745
- Quadrelli, R., and Peterson, S. (2007). The energy–climate challenge: Recent trends in CO2 emissions from fuel combustion. *Energy Policy* 35, 5938–5952. doi:10.1016/j.enpol.2007.07.001
- Rai, K., and Garg, B. (2022). Dynamic correlations and volatility spillovers between stock price and exchange rate in BRICS economies: Evidence from the COVID-19 outbreak period. *Appl. Econ. Lett.* 29, 738–745. doi:10.1080/13504851.2021.1884835
- Rangel, J. G., and Engle, R. F. (2012). The Factor-Spline-GARCH model for high and low frequency correlations. *J. Bus. Econ. Stat.* 30, 109–124. doi:10.1080/07350015.2012.643132
- Reboredo, J. C. (2018). Green bond and financial markets: Co-Movement, diversification and price spillover effects. *Energy Econ.* 74, 38–50. doi:10.1016/j.eneco.2018.05.030
- Reboredo, J. C. (2012). Modelling oil price and exchange rate co-movements. *J. Policy Model.* 34, 419–440. doi:10.1016/j.jpmodel.2011.10.005
- Reboredo, J. C., Ugolini, A., and Aiube, F. A. L. (2020). Network connectedness of green bonds and asset classes. *Energy Econ.* 86, 104629. doi:10.1016/j.eneco.2019.104629
- Reboredo, J. C., and Ugolini, A. (2020). Price connectedness between green bond and financial markets. *Econ. Model.* 88, 25–38. doi:10.1016/j.econmod.2019.09.004
- Ren, X., Li, Y., yan, C., Wen, F., and Lu, Z. (2022). The interrelationship between the carbon market and the green bonds market: Evidence from wavelet quantile-on-quantile method. *Technol. Forecast. Soc. Change* 179, 121611. doi:10.1016/j.techfore.2022.121611
- Ren, X., Lu, Z., Cheng, C., Shi, Y., and Shen, J. (2019). On dynamic linkages of the state natural gas markets in the USA: Evidence from an empirical spatio-temporal network quantile analysis. *Energy Econ.* 80, 234–252. doi:10.1016/j.eneco.2019.01.001
- Saboori, B., Al-mulali, U., bin Baba, M., and Mohammed, A. H. (2016). Oil-Induced environmental Kuznets curve in organization of petroleum exporting countries (OPEC). *Int. J. Green Energy* 13, 408–416. doi:10.1080/15435075.2014.961468
- Sadorsky, P. (2014). Modeling volatility and conditional correlations between socially responsible investments, gold and oil. *Econ. Model.* 38, 609–618. doi:10.1016/j.econmod.2014.02.013
- Sadorsky, P. (2009). Renewable energy consumption, CO2 emissions and oil prices in the G7 countries. *Energy Econ.* 31, 456–462. doi:10.1016/j.eneco.2008.12.010
- Saeed, T., Bouri, E., and Alsulami, H. (2021). Extreme return connectedness and its determinants between clean/green and dirty energy investments. *Energy Econ.* 96, 105017. doi:10.1016/j.eneco.2020.105017
- Saeed, T., Bouri, E., and Tran, D. K. (2020). Hedging strategies of green assets against dirty energy assets. *Energies (Basel)* 13, 3141. doi:10.3390/en13123141
- Salem, S. (2017). *Key commodity markets: Dynamic correlations & volatilities in time-frequency domain*. Surrey: University of Surrey United Kingdom.

- Sener, S. E. C., Sharp, J. L., and Anctil, A. (2018). Factors impacting diverging paths of renewable energy: A review. *Renew. Sustain. Energy Rev.* 81, 2335–2342. doi:10.1016/j.rser.2017.06.042
- Singhal, S., and Ghosh, S. (2016). Returns and volatility linkages between international crude oil price, metal and other stock indices in India: Evidence from VAR-DCC-GARCH models. *Resour. Policy* 50, 276–288. doi:10.1016/j.resourpol.2016.10.001
- Surya, E., and Wibowo, S. S. (2018). Empirical analysis of oil price volatility and stock returns in ASEAN-5 countries using DCC-GARCH. *Pertanika J. Soc. Sci. and Humanit.* 26, 251–263.
- Syed, A. A., Ahmed, F., Kamal, M. A., Ullah, A., and Ramos-Requena, J. P. (2022). Is there an asymmetric relationship between economic policy uncertainty, cryptocurrencies, and global green bonds? Evidence from the United States of America. *Mathematics* 10, 720. doi:10.3390/math10050720
- Tiwari, A. K., Aikins Abakah, E. J., Gabauer, D., and Dwumfour, R. A. (2021). Green bond, renewable energy stocks and carbon price: Dynamic connectedness, hedging and investment strategies during COVID-19 pandemic. *SSRN J.*, 1–42. doi:10.2139/ssrn.3897284
- Troster, V., Shahbaz, M., and Uddin, G. S. (2018). Renewable energy, oil prices, and economic activity: A granger-causality in quantiles analysis. *Energy Econ.* 70, 440–452. doi:10.1016/j.eneco.2018.01.029
- Tse, Y. K., and Tsui, A. K. C. (2002). A multivariate generalized autoregressive conditional heteroscedasticity model with time-varying correlations. *J. Bus. Econ. Stat.* 20, 351–362. doi:10.1198/073500102288618496
- Turhan, M. I., Sensoy, A., and Hacihasanoglu, E. (2014). A comparative analysis of the dynamic relationship between oil prices and exchange rates. *J. Int. Financial Mark. Institutions Money* 32, 397–414. doi:10.1016/j.intfin.2014.07.003
- Uzar, U. (2020). Political economy of renewable energy: Does institutional quality make a difference in renewable energy consumption? *Renew. Energy* 155, 591–603. doi:10.1016/j.renene.2020.03.172
- van Eck, N. J., and Waltman, L. (2017). Citation-based clustering of publications using CitNetExplorer and VOSviewer. *Scientometrics* 111, 1053–1070. doi:10.1007/s11192-017-2300-7
- Wang, S., and Wang, D. (2022). Exploring the relationship between ESG performance and green bond issuance. *Front. Public Health* 10, 897577. doi:10.3389/fpubh.2022.897577
- Yan, L., Wang, H., Athari, S. A., and Atif, F. (2022). Driving green bond market through energy prices, gold prices and green energy stocks: Evidence from a non-linear approach. *Econ. Research-Ekonomika Istraz.*, 1–21. doi:10.1080/1331677X.2022.2049977
- Zaghdoudi, T. (2017). Oil prices, renewable energy, CO2 emissions and economic growth in OECD countries. *Econ. Bull.* (3) 37, 1844–1850. Available at: <https://www.scopus.com/inward/record.uri?eid=2-s2.0-85028668466&partnerID=40&md5=d2530f8e0feb8e695f473eebbe41a2f3>.
- Zheng, Y., Zhou, M., and Wen, F. (2021). Asymmetric effects of oil shocks on carbon allowance price: Evidence from China. *Energy Econ.* 97, 105183. doi:10.1016/j.eneco.2021.105183