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Driving green bond market through energy prices, gold prices and green energy stocks: evidence from a non-linear approach

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ABSTRACT

One of the most controversial concerns among the researchers is the expansion of the green bond markets, so as to reduce environmental pollution. The present study estimates the factors that help drive the global green bond markets, such as energy prices, gold prices, and green energy stocks. The study has applied Quantile Autoregressive Lagged Approach (QARDL) and Quantile Granger Causality test to estimate the causal relationship among the variables for January 2010 and June 2021. The QARDL findings reveal that for all the quantiles, the error correction term is statistically significant with the predicted negative sign. This confirms the existence of a strong long-run equilibrium relationship between the relevant variables and the green bonds market on a global level. The findings revealed that gold and energy prices have a lower effect on the green bonds market on every quantile, and also from the low to medium quantiles, respectively. While at the same time, the green energy stocks have an increasing effect on the green bonds market at higher quantiles. The results of the causal examination using Granger-causality in quantiles show a bi-directional causal relationship between the green bonds, energy prices, gold prices, and green energy stocks in the world economy.

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1. Introduction

A climate change adaptation or a minimal carbon economy is one of the key goals of environmentalists and government agencies around the world (Ji et al., 2021; Ji et al., 2021; Umar et al., 2021). In this regard, several efforts have already been made to attain this goal, and green projects financing, including mutual funds and investments based on sustainability (Capelli et al., 2021; Ferrat et al., 2022), green investments,

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and divestment from fossil fuels, are among some of the initiatives that have already been introduced to encourage the transition towards green economies (Naqvi et al., 2021). In addition to this, Green bonds (GB) are among the most popular techniques to support green environment projects. A green bond is a unique financial product that is defined as a 'the use proceeds' criterion that requires the funds generated through its issuance to contribute towards climate change remediation, conservation of the natural resource, biodiversity enhancement or conservation, pollution control and prevention, and so on (C.-W. Su et al., 2021; Z.-W. Su et al., 2021). GBs are essentially unique, sustainability-oriented, fixed-income financial instruments that allow issuers to grow funds that are exclusively dedicated to environmentally beneficial initiatives, in line with a climate-resilient economy (Yan et al., 2022; Yu et al., 2022). Green bonds, more specifically, offer significant environmental benefits due to their green character, such as being energy-efficient, low on carbon, and climate-friendly (Park et al., 2020; Rizvi et al., 2021; Sartzetakis, 2021). This subject belongs to the developing body of knowledge in the field of energy finance, which includes sustainable finance and green finance (Guo et al., 2022; Ji et al., 2021).

This structure enables the local and global environmental organisations to increase funds by selling fixed income securities, which are then used to fund sustainable and environmentally beneficial projects (Chien et al., 2022; Naeem et al., 2021; C.-W. Su et al., 2021). In the long run, financing through a substantial bond market that can provide capital may thus be appropriate, and also, green bonds are a reliable source of long-term income for investors. Green bonds can essentially be studied by focusing on the general qualities of the bonds, and the bond market's relationship with the stock market has long been a source of study interest among researchers. In this regard, The bond's volatility spill-over mechanism is passed on to other traditional assets, which play a significant role in portfolio composition and risk management (Chien et al., 2021; Ielasi et al., 2018). Because green bonds are a type of bond, understanding how they are interconnected to other assets can help international investors to better structure their relevant portfolios (Hung, 2021; Lobato et al., 2021; C.-W. Su et al., 2020).

The World Bank and the Swedish bank (SEB) issued the first GB in the year 2008, which has since then experienced an expansion of its international market from 11\$ in the year 2013 and 36\$billion in the year 2014, to \$167 billion in the year 2018 (Maltais & Nykvist, 2020). Green bond markets have grown in popularity in the recent years across the globe in order to provide an opportunity for sustainable and long-term infrastructure financing. According to Flammer (2020), this quick development is referred to as the global financial market's 'green bond boom.' According to multilateral development banks (European Investment Bank and World Bank), the issuance of GB has punctually been extended to all investors, e.g., institutional investors, commercial banks, municipalities, and a few of the largest organisations of the world (Umar et al., 2021). There has been an augmented and rapid round investments of about more than ten folds in the last five years in these new and expeditiously growing fixed-income instruments, and these are projected to reach an astonishing one trillion US dollars because of the increase in the demand for green bonds (Umar et al., 2021).

Table 1. Issuance of GBs by World Regions (2012–2018).

Global regions	No of countries	No of green bonds issuers	Volume (Billion \$)
Africa	4	8	1.5
East Asia and Pacific	7	160	112.3
Europe and Central Asia	5	9	3.2
Latin America and the Caribbean	8	32	14.1
Middle East and North Africa	3	6	1.0
South Asia	1	20	7.7
Total	2	235	139.7

Source: International Finance Cooperation (IFC).

As per the climate bonds initiative database, the GB issuance has a stunning yearly growth of more than 113 percent, as it increased from one to more than two thousand from the years pertaining to 2007 to 2017. In the year 2017, China, France, and the United States accounted for 56 percent of the total issuance of global green bonds. According to this database, developing nations, on the other hand, have been left out of this rising source of climate capital that they require to carry out their climate change mitigation and adaptation plans (Umar et al., 2021). Therefore, only a limited number of governments and investors from these economies have issued GBs thus far. Nonetheless, an increasing number of them are gradually focussing on this market, which is influenced by various factors (Banga, 2019; Nawaz et al., 2021). East Asia & Pacific has the largest GB market among other geographical regions, and South Asia has had the second-largest green bond market expansion from the year 2012 to 2018, at 7.7 billion US dollars, as cited in Anh Tu et al. (2020). To validate this, Table 1 shows the issuance of green bonds in various regions of the world, over a time period stretching from 2012 to 2018.

Despite the fast expansion of the GB market, it has had a significant impact on the debt financing expenditures and the financial conditions (Deschryver & De Mariz, 2020; Flammer, 2020; Kaiser & Welters, 2019; Karim et al., 2022; Lobato et al., 2021). The GB market expansion in various countries is a contentious topic among the top academics. Several researchers such as (Partridge & Medda, 2020; Shair et al., 2021; Voica et al., 2015), have suggested that investors and government bodies are the main players of the GB market, and that they determine the growth level of the GB market. whereas some researchers have also suggested that there is a plethora of factors that tend to have an impact on the development of the GB market (Broadstock & Cheng, 2019; Ehlers & Packer, 2017; Flammer, 2020; Reboredo & Ugolini, 2020; Sun et al., 2021; Zerbib, 2019). (Broadstock & Cheng, 2019; Ehlers & Packer, 2017; Flammer, 2020; Reboredo & Ugolini, 2020; Sun et al., 2021; Zerbib, 2019), for instance, describe the impact of capital markets and macroeconomic determinants on the GB market. Furthermore, some studies, such as, (Bhattacharya et al., 2015; Della Croce & Yermo, 2013), claim that investment facilities can successfully promote the growth of the GB market. As a result, it has been obvious that the GB market's growth depends on a number of interconnected elements, making its development multi-dimensional in nature (Anh Tu et al., 2020; Chien et al., 2022).

Despite the fast expansion of the GB market, it has had a significant impact on debt financing expenditures and financial condition (Curley, 2014; Deschryver & De Mariz, 2020; Flammer, 2020; Tang & Zhang, 2020). GB market expansion in

countries is a contentious topic among academics. Several researchers, like (Partridge & Medda, 2020; Shair et al., 2021; Voica et al., 2015), suggest that investors and government bodies are the main players of the GB market and that they determine the growth level of the GB market, whereas some researchers suggest that various factors have an impact on the development of the GB market (Broadstock & Cheng, 2019; Ehlers & Packer, 2017; Flammer, 2020; Reboredo & Ugolini, 2020; Sun et al., 2021; Zerbib, 2019). (Broadstock & Cheng, 2019; Ehlers & Packer, 2017; Flammer, 2020; Reboredo & Ugolini, 2020; Sun et al., 2021; Zerbib, 2019) for example, describe the impact of capital markets and macroeconomic determinants on the GB market. Furthermore, some studies, e.g., (Bhattacharya et al., 2015; Della Croce & Yermo, 2013), claim that investment facilities can promote the growth of the GB market. As a result, it is obvious that the GB market's growth depends on a number of interconnected elements, making its development multi-dimensional (Anh Tu et al., 2020; Chien et al., 2022).

The significance of the expansion of the GB market and the presence of many influencing variables on this expansion necessitates a thorough examination of prioritising the influencing elements (Anh Tu et al., 2020). However, the relationship of oil price and green bond dynamics receives little attention in the studies. The awareness of their interactions is necessary for the investors since it can help them reap the benefits of a diverse portfolio and illustrate how oil market volatility affects green bond pricing (Lee et al., 2021). Inflationary pressures are created in global markets as oil prices rise. Higher price inflation has a major impact on the cash flow discount rate, resulting in lower stock values (Kocaarslan & Soytas, 2019). There is also a scarcity of empirical evidence connecting green bonds to the commodity market (Kanamura, 2020; Reboredo & Ugolini, 2020). However, whereas previous research has focussed on the connection between GB and energy commodities, there is little knowledge about the dynamic causality of GB to diverse types of commodities. The study of Dutta et al. (2021) and Brooks and Prokopczuk (2013) justify the use of different commodities, as they claim there is a lot of variation in the behaviour of individual commodities (Naeem et al., 2021; Zhuang et al., 2021).

The main goal of our study is to estimate the association between GB and specific commodities. Since the focus of previous empirical research has been on examining the relationship between GB and the general index of energy commodity, e.g., (Reboredo, 2018; Reboredo & Ugolini, 2020), we add to the existing body of literature by focussing on three groups of commodity: green energy stocks, energy price (oil price) and gold price. Our empirical research, as expected, reveals a significant variance in the behaviour of the GB market corresponding to these commodities, explaining why these commodities have different features (Chong & Miffre, 2009; Erb & Harvey, 2006). Second, because economic variables have non-linear patterns due to their underlying scattered features, we believe that green bonds are non-linearly related to gold prices, energy prices, and green energy stocks. Hence, we contribute to the empirical literature by presenting a non-linear econometric model as the optimum framework to explain the relationships in the study, as existing research that uses a linear approach may result in erroneous conclusions. In this vein, this study investigates this link using a comprehensive and appropriate econometric

methodology, i.e., QARDL (Quantile Autoregressive Distributed Lag Model). This technique aims to simultaneously find long-run and short-run relationships in green energy bonds while accounting for any potential asymmetric and nonlinear associations in green energy stocks, oil price, and gold price (Umar et al., 2020). Additionally, this econometric methodology enables an in-depth exploration of variance in the quantile of GB by establishing linkage with gold prices, energy prices, and green energy stocks.

The remainder of the study is ordered as follows: Section 2 gives a review of the existing literature. The data and econometric methodology is provided in Section 3. Empirical findings and their discussion are given in section 4. Our study concludes in Section 5.

2. Literature review

GBs and various relevant energy and financial asset categories are the subjects of the research's new and fast-increasing strand. Although there are several research studies on the interaction between GBs and assets and energy asset markets, empirical investigations evaluating the non-linear associations between GBs and commodities and energy markets are still limited as per the available literature (Li et al., 2021; Mohsin et al., 2021). For instance, Reboredo (2018) used bivariate copula models to investigate the interrelated movement of the international GB market with a collection of conventional energy and financial markets, and the author argued that GB was closely associated with corporate bonds of treasury and grade investment, but only marginally to energy and stock commodity market (Reboredo, 2018). Using the technique of wavelet coherence and rolling window wavelet correlation, Nguyen et al. (2021) studied the connections between GBs and some other asset categories across time and across investment horizons, including common and clean energy equities, conventional bonds, and commodities (Umar et al., 2021). Across nearly all time frames and frequencies, they found strong comovement between GB and regular bonds and, to a lesser degree, between GBs and substitute stocks of energy. However, green bonds were observed to have a weak correlation with common stocks and commodities and confirmed that green bonds are safe havens (Nguyen et al., 2021). Similarly, by employing the Diebold Yilmaz technique and the connectedness model of Baruník and Křehlík (2018), and Le et al. (2021) estimated the frequency and time volatility connectedness across cryptocurrencies, fintech stocks, GBs, and other conventional assets, including gold, USA dollar, general stocks, VIX volatility index and crude oil (Umar et al., 2020). The results indicated that volatility is predominantly transmitted across various markets in the short run, and GBs tend to be net recipients of shocks in volatility (Le et al., 2021).

In the framework of the fourth industrial revolution, (Huynh, 2020) investigated tail dependency and volatility interconnectivity along with a range of conventional and new asset categories, such as stocks of robotics firms and artificial intelligence, overall stocks, GBs, crude oil, gold, Bitcoin, and the VIX index. Copula functions and Baruník and Křehlík (2018) connectedness technique was used for this purpose. The research showed that portfolios including these asset types had a high degree of heavy

tail reliance, meaning a higher likelihood of great joint losses in times of economic and financial chaos. In addition, short-run volatility transmission was larger than long-run volatility transmission, and bitcoin and gold were essential hedging assets (Huynh et al., 2020). According to Le et al. (2021), bitcoin and gold substantially impacted green bonds and NASDAQ AI (Le et al., 2021). While Liu et al. (2021) proposed a positive and significant normal and tail dependency between clean energy and GB markets, they also proposed a positive dynamic normal and tail dependency between GBs and other conventional financial markets (Liu et al., 2021).

Dutta et al. (2021) applied GARCH Based Quantile Regression on daily data, and their findings showed that risk was considerably transmitted from silver, gold, and crude oil markets to multiple green stock indices in India. During the bearish stock market period, the influence of commodities market influence transmission was stronger than during bullish stock market periods, implying that green stock indices are more likely to get instability from precious metal and energy markets (Dutta et al., 2021). Azhgaliyeva et al. (2021) made an examination of the oil price shocks affect on the issuance of green bonds in private using the multilevel longitudinal random intercept and random coefficient models. Their empirical analysis found that oil supply shocks had positive effects on green bond issuance in contrast to the general market. It was also observed that the issue of sovereign GBs in the public market tended to encourage the issuing of GBs in the private market (Azhgaliyeva et al., 2021).

Applying the spill-over frameworks proposed by Diebold and Yılmaz (2014) and Baruník and Křehlík (2018), Naeem et al. (2021) explored the asymmetrical connectedness between GBs and commodities in the temporal and frequency domains. The findings showed asymmetric spill-overs between assets over time and across frequency cycles. Although spill-over was higher for commodities in the same class, silver and gold had the strongest links to green bonds across all time periods. On the other hand, crude oil had a strong long-term correlation with green bonds (Naeem et al., 2021). In another study by them using the Cross-Quantilegram approach, they tried to document asymmetric association between GBs and metals, agriculture, and energy. They discovered the greatest hedging advantage of GBs against variations of natural gas, various agricultural products, and industrial metals, as indicated by the non-correlation or negative association with the commodities in moments of higher volatility (Naeem et al., 2021). (Kanamura, 2020) investigated the greenness of green bonds and their performance with regard to energy, concluding that energy and environmental values were positively related. As a result, it was suggested that greenness was factored into the Bloomberg Barclays MSCI and S and P green bond indexes (Kanamura, 2020).

Applying structural VAR models (Reboredo & Ugolini, 2020) evidenced that GBs had a weak relationship with energy possessions and equities, implying diversification benefits. Moreover, it was found that GBs were little affected by equity and energy markets return spill-overs (Reboredo & Ugolini, 2020). Under exceptional and market situations applying Quantile VAR, Saeed et al. (2020) examined return spill-overs between GBs, renewable energy equities, and different unclean energy assets, e.g., oil and gas businesses and crude oil stocks. Spill-overs were found strong, particularly in

the upper and lower quantiles (Saeed et al., 2020). Bachelet et al. (2019) found that GBs had higher liquidity than GBs issued by institutional issuers, whereas GB produced by the private issuers had higher liquidity and variability than institutional bonds. Financial market unpredictability, oil prices, uncertainty in economic policies, and negative and positive news stories all influence the relationship between the two markets (Bachelet et al., 2019).

These studies are significant since they look into the properties of green bonds, including their performance and the relationship between GBs and other markets. Studies found it crucial to demonstrate the interconnectedness between the GBs market and other markets at various frequency intervals, while some studies preferred frequency and time-based techniques that can reveal the directional connectedness of diverse frequency horizons and time. Tail dependency and connectedness appear to be more of focus in some studies. It is revealed in the existing literature that prior studies had not mutually estimated the long-run and short-run causality between the oil prices, gold prices, green energy stocks, and green bonds. To fill in this research gap, we applied the QARDL methodology. As mentioned in the introduction part, this methodology can also solve some of the challenges that other non-linear approaches experience.

3. Data and methodology

The effect of gold prices, oil prices, and green energy stocks on the green bonds market has been examined in this study from 01 Jan 2010 to 30 June 2021 for Turkey. For this purpose, we use green bond markets (GB), gold Price (GP), oil price (EP), and green energy stocks (CLEAN). THE S&P GB index (SPGB) is considered the principal variable in this study sourced from Bloomberg. Other variables included in the study are the WilderHill clean energy index (WCEI), gold price, and oil price, all sourced from Bloomberg. The WilderHill clean energy index consists of the USA's publically traded company stocks occupied in developing clean energy and energy conservation business. The S&P Green Bond Index comprises 5 series: S&P GB Index, the S&P 500 Composite Index, S&P Clean Energy Index, the S&P GSCI Commodity Index, and Barclays Bloomberg Global Treasury Index (BCONV). The GBs market is represented by S&P GB Index (SPGRNB). The range of our daily data is from 01/01/2010 to 30/06/2021. The sample period start date is determined based on the S&P GB index data.

Following the line of the study of Reboredo and Ugolini (2020), Dutta et al. (2021), Kanamura (2020), Naeem et al. (2021), and Azhgaliyeva et al. (2021), the econometric model of the study is specified as follows:

$$GB = \alpha + \beta_1 GP + \beta_2 EP + \beta_3 CLEAN + \varepsilon_t \quad (1)$$

Where GB is the green bond market, GP is gold price, EP is the oil price, and CLEAN is the green energy stocks measured as clean energy stocks and ε_t is the error term.

3.1. The QARDL model

To estimate the non-linear relation between the green bonds market, oil prices, gold prices, and green energy stocks, the latest QARDL methodology introduced by Cho et al. (2015) has been applied in this study. Specifically, the QARDL methodology allows examining the long-run quantile equilibrium effect of the gold price, oil price, and green energy stocks on green bond markets in the world. Additionally, this econometric methodology enables an in-depth exploration of variance in the quantile of GB by establishing linkage with gold prices, energy prices, and green energy stocks. Wald test is applied to further check the measures of parameter dependability in each quantile for the long-run and short-run equilibrium both. At first, the conventional linear ARDL model is described as follows:

$$GB_t = \alpha + \sum_i^p \beta_1 GB_{t-i} + \sum_i^q \beta_2 GP_{t-i} + \sum_i^r \beta_3 EP_{t-i} + \sum_i^s \beta_4 CLEAN_{t-i} + \epsilon_t \quad (i)$$

Where ϵ_t is the error term which is represented by the lowest field generated by $\{GB_t, GP_t, EP_t, CLEAN_t, G_{t-1}$, where p, q, r , and s show the lag order selected through SIC (Schwarz Information Criterion), in addition, $GB_t, GP_t, EP_t, CLEAN_t$, refer to the natural log of green bonds market, gold price, oil price, and green energy stocks respectively, the following framework of the QARDL approach is suggested by the rewriting of eq (i) to a quantile context:

$$Q_{\Delta GB_t} = \alpha(\tau) + \rho GB_{t-i} + \phi_1 GP_{t-i} + \phi_2 EP_{t-i} + \phi_3 CLEAN_{t-i} + \sum_i^p \beta_1(\tau) GB_{t-i} \\ + \sum_i^q \beta_2(\tau) GP_{t-i} + \sum_i^r \beta_3(\tau) EP_{t-i} + \sum_i^s \beta_4(\tau) CLEAN_{t-i} + \epsilon_t(\tau) \quad (ii)$$

where $\epsilon(\tau) = GB_t - Q_{GB_t}(\frac{\tau}{\epsilon_t - 1})$ and $0 < \tau < 1$ is the quantile (Troster, 2018). To execute data analysis, the successive pair of quantiles τ are used that belong to $\{0.05, 0.10, 0.20, 0.30 \dots 0.90$ and $0.95\}$. Moreover, the comprehensive QARDL model is given in eq (ii).

$$Q_{\Delta GB_t} = \alpha(\tau) + \rho GB_{t-i} + \phi_1 GP_{t-i} + \phi_2 EP_{t-i} + \phi_3 CLEAN_{t-i} \\ + \sum_i^p \beta_1(\tau) GB_{t-i} + \sum_i^q \beta_2(\tau) GP_{t-i} + \sum_i^r \beta_3(\tau) EP_{t-i} \\ + \sum_i^s \beta_4(\tau) CLEAN_{t-i} + \epsilon_t(\tau) \quad (iii)$$

Furthermore, the preceding eq (iii) can be updated to get the following error correction model for the QARDL framework measurement:

$$\begin{aligned}
 Q\Delta GB_t &= \alpha (\tau) \\
 &+ \rho(\tau)GB_{t-i} (-\omega_1 (\tau)GP_{t-i} - \omega_2 (\tau)EP_{t-i} - \omega_3 (\tau)CLEAN_{t-i}) \\
 &+ \sum_{i=1}^{p-1} \beta_1 (\tau)\Delta GB_{t-i} + \sum_{i=0}^{q-1} \beta_2 (\tau)\Delta GP_{t-i} + \sum_{i=0}^{r-1} \beta_3(\tau)\Delta EP_{t-i} \\
 &+ \sum_{i=0}^{-1} \beta_4(\tau)\Delta CLEAN_{t-i} + \varepsilon_t(\tau)
 \end{aligned} \tag{iv}$$

The Δ technique is utilised to estimate the combined short-run effect of the previous GB market on the current GB market, which is evaluated by $\beta_* = \sum_{i=1}^{p-1} \beta_1$. A similar process is used to assess the residual increasing short-run influence of prior and current on the current level of the gold price, oil price, and green energy stocks on the green bonds market. last, in eq (iii), the coefficient of the speed of adjustment must be significantly negative (Cho et al., 2015).

Finally, the Wald test is applied (with specific null and alternative hypotheses for short-run and long-run parameters), which follows the Chi-Squared distribution asymptotically for the statistical investigation of the short run and the long-run asymmetric and non-linear effects of green energy stock, gold price, oil price on GB markets in the short run and long run both. Small numbers of motivating facts emerge after the prior equations (Cho et al., 2015). The long-run and short-run values may be quantile-based at first, implying that the QARDL method coefficients may differ on every quantile, indicating that these coefficients could be modified at any time. The Wald test can also be used to check the limits of the short and long-term coefficients within and between quantiles (Cho et al., 2015). Wald Test is used to examine the null and alternative hypotheses for the parameters of short-run and long-run such as \emptyset^* , ω^* , β^* and ρ^* given below:

$$H_0^\emptyset = F\emptyset_* (\tau) = f \text{ verses } H_1^\emptyset : F \emptyset_* (\tau) \neq f$$

$$H_0^\omega = S\omega_* (\tau) = s \text{ verses } H_1^\omega : S \omega_* (\tau) \neq s$$

$$H_0^\beta = S\beta_{i*} (\tau) = s \text{ verses } H_1^\beta : S \beta_{i*} (\tau) \neq s$$

$$H_0^\rho = S\rho_{i*} (\tau) = s \text{ verses } H_1^\rho : S \rho_{i*} (\tau) \neq s$$

Where F and f are h^*ps and h^*l , referred to as pre-defined matrices. S and s are h^*s and h^*l , the pre-specified matrices with h being the restriction number. i denotes EP, GP, and CLEAN, respectively. Wald test is specifically applied to investigate the non-linearities on the adjustment speed parameter and integrating parameter of the long run (He et al., 2021). Four tests are run for every group and every parameter.

Table 2. Descriptive statistics results.

Variables	Mean	Min	Max	Std. Dev.	J-B Stats
GB	0.0251	0.0142	0.0384	1.043	55.008***
GP	0.0891	0.0524	0.1289	0.024	42.019***
EP	0.0534	0.0327	0.0693	1.053	28.014***
CLEAN	0.0420	0.0201	0.1251	0.014	37.020***

The asterisks *, ** and *** show 10%, 5% and 1% level significance levels respectively.

Source: Author's Estimation.

3.2. Quantile granger causality test

The literature has indeed investigated whether a variable is a predecessor to some other variable by using Granger's (1969) causality analysis approach. The Granger causality test, in general, implies that the present value of the explained variable is affected by its own value and the lagged values of the explanatory variables. Many novel causality tests were created after (Granger, 1969) using diverse methodologies. We use the quantile granger causality approach that (Troster, 2018) introduced recently to investigate the quantile causal of GB markets with the gold price, energy price, and green energy stocks in the current study. Granger (1969) states that a variable (X_i) does not granger cause another variable (Y_i) if the prior X_i does not help in the estimation of Y_i , resulting in the previous Y_i . an explained vector is supposed $(N_i^Y, N_i^X)' \in R^c$, $s = o + q$, where N_i^X is the earlier indication group of X_i $N_{ix} = (X_{i-1}, \dots, X_{i-q})' \in R^q$. Furthermore, the H_0 of granger non causality from one variable X_i to other variable Y_i is described in the current study as follows:

$$H_0^{X-Y} : F_y (yN_i^Y, N_i^X) = F_y (yN_i^Y), \text{ for all } y \in R \quad (v)$$

Where provisional distribution purpose of Y_i is $F_y (\cdot | N_i^Y, N_i^X)$ provided that (N_i^Y, N_i^X) . The DT check is applied by the classification of the QAR method $m(\cdot)$ for whole $\pi \in \subset \Gamma [0,1]$, which is based on the H_0 of no granger causality relationship as below.

$$QAR(1) : m^1 (N_i^Y, \partial(\pi)) = \lambda_1(\pi) + \lambda_2(\pi) X_{i-1} + \mu_2 \Omega_Y^{-1}(\pi) \quad (vi)$$

We estimate the coefficients $[\partial(\pi) = (\lambda_1(\pi) \lambda_2(\pi))]$ and μ_t through maximum likelihood in equal quantile points, and $-\Omega_Y^{-1}(\cdot)$ is the reverse of a usual fundamental distribution function. Our study evaluates the QAR approach in eq (vi) to confirm causality between the components with lagged to alternative factors. Lastly, the QAR(1) equation with the help of eq (vi) is given below:

$$Q_\pi^Y (Y_i N_i^Y, N_i^X) = \lambda_1(\pi) + \lambda_2(\pi) Y_{i-1} + n(\pi) X_{i-1} + \mu_2 \Omega_Y^{-1}(\pi) \quad (7)$$

4. Results and discussion

Now we proceed to the interpretation and discussion of the empirical analysis. First, it is necessary to provide descriptive statistics and check the series' stationarity

Table 3. Unit root test results.

Variables	ADF (Level)	ADF (Δ)	ZA (Level)	Break Year	ZA (Δ)	Break Year
GB	-0.035	-4.552***	-1.210	16/06/2016	-9.982***	11/08/2010
GP	-1.062	-5.696***	-2.571	09/08/2020	-7.531***	27/03/2015
EP	-0.051	-3.012***	-1.426	21/01/2021	-6.010***	09/11/2012
CLEAN	-2.073	-6.648***	-2.472	02/05/2015	-8.267***	15/04/2016

Note: the values specify statistical values of the ADF and ZA test in the table. The asterisk *, ** and *** show 10%, 5% and 1% level of significance respectively.

Source: Author's Estimation.

features before proceeding to QARDL analysis. Table 2 provides the results of the descriptive statistics of our selected variables, i.e., GB, EP, GP, and CLEAN. It is indicated from the results that the average gold price (GP) is the highest among all the variables in Turkey. At the same time, oil price (EP) has the highest variability about the mean among all the variables. 'Jarque-Bera normality test' developed by Jarque and Bera (1980), is performed to test data abnormality. The null hypothesis of this test states the normality of data, and the alternative hypothesis states the reverse. The H_0 of normal distribution of the Jarque-Bera test is rejected for every series under-study at a 1% level of significance. Thus, the application of quantile estimation techniques is considered necessary and suitable for our study following Godil et al. (2021), Godil et al. (2020), Chang et al. (2020), and Suki et al. (2020).

Since the series are not normally distributed, the unit root in quantile test techniques is followed instead of conventional unit root test techniques (such as Phillips & Perron and Augmented Dickey-Fuller test for unit root, etc.) to get robust inference and unbiased results. The unit root test results of our variables of the study at quantiles are reported in Table 3. It is evidenced from the results that all the variables are nonstationary at the level and become stationary by taking the first difference. So a unique integration order is found between the variables in this analysis.

The estimation findings of the QARDL model are given in Table 4. The quantiles ranging from 0.05- 0.30 are classified as the bearish market situation, 0.40 – 0.60 are considered the normal market situation, and from 0.70 – 0.95 are considered the bullish market situation. The findings reveal that the coefficient for adjustment speed (ρ^*) is significant and negative at every quantile, demonstrating that the green bond markets, gold price, oil price, and green energy markets have reverted to long-run equilibrium. More specifically, the adjustment speed has the highest value in the last quantile. The symbol β 's in Table 3 shows the long-run relationships of independent variables (GP, EP, CLEAN) with the dependent variable (GB).

The coefficient of GP is negative, which shows that a downward trended long-term relation of GP and GB exists at all quantiles, while the level of significance of GP is progressively increasing as we move towards higher quantiles. Although in the upper quantiles, the long-run relationship of EP with GB is statistically insignificant, the results indicate the significant negative impact of EP on GB up to a medium-range of quantiles, i.e., (0.05–0.50). In another way, increasing oil prices will decrease the investment in GB in the long run during bearish and normal market conditions.

In contrast, the empirical findings reveal that the long-run coefficient of green energy stock (CLEAN) positively affects GB. However, the magnitude of impact and level of significance of green energy stocks are different at different quantiles. Over

Table 4: Results of QARDL estimations.

Quantiles (τ)	Constant $\alpha_-(\tau)$	ECM $\rho_-(\tau)$	Long Run Estimation			Short Run Estimation			
			$\beta_{GP}(\tau)$	$\beta_{EP}(\tau)$	$\beta_{CLEAN}(\tau)$	$\varphi_1(\tau)$	$\omega_0(\tau)$	$\lambda_0(\tau)$	$\theta_0(\tau)$
0.05	0.021 (0.005)	-0.238*** (-5.054)	-0.230* (-1.646)	-0.110** (-2.509)	0.350 (1.634)	0.521*** (18.227)	-0.022** (-2.215)	-0.048*** (-3.291)	0.005 (0.661)
0.10	0.012 (0.009)	-0.211*** (-5.013)	-0.244* (-1.853)	-0.111*** (-3.207)	0.361 (1.628)	0.530*** (15.021)	-0.019** (-2.322)	-0.039*** (-3.001)	0.023 (1.565)
0.20	0.018 (0.004)	-0.209*** (-5.220)	-0.231* (-1.800)	-0.006*** (-3.710)	0.345 (1.638)	0.560*** (19.223)	-0.013** (-2.016)	-0.048** (-2.579)	0.037* (1.648)
0.30	0.025 (0.007)	-0.227*** (-5.416)	-0.265** (-1.994)	-0.112*** (-3.108)	0.367* (1.648)	0.542*** (8.034)	-0.028** (-1.999)	-0.049** (-1.971)	0.021* (1.809)
0.40	0.019 (0.010)	-0.264*** (-5.746)	-0.242** (-2.192)	-0.108*** (-3.211)	0.356* (1.766)	0.551*** (13.468)	-0.039 (-1.513)	-0.040* (-1.753)	0.041* (1.745)
0.50	0.007 (0.001)	-0.315*** (-4.836)	-0.224** (-2.398)	-0.115** (-2.104)	0.339** (1.983)	0.519*** (9.054)	-0.020 (-0.828)	-0.040* (-1.818)	0.011* (1.691)
0.60	0.017 (0.003)	-0.325*** (-5.053)	-0.236** (-2.794)	-0.081 (-1.506)	0.359** (1.994)	0.543*** (10.675)	-0.044 (-1.214)	-0.042* (-1.650)	0.042** (1.968)
0.70	0.010 (0.002)	-0.313*** (-4.660)	-0.241*** (-2.994)	-0.055 (-1.212)	0.351*** (2.994)	0.567*** (13.864)	-0.029 (-0.634)	-0.018 (-1.482)	0.034** (1.993)
0.80	0.016 (0.005)	-0.331*** (-3.549)	-0.256*** (-3.002)	-0.109 (-1.003)	0.365*** (3.004)	0.531*** (9.431)	-0.050 (-0.826)	-0.019 (-1.521)	0.027** (1.989)
0.90	0.011 (0.008)	-0.324*** (-4.257)	-0.250*** (-2.995)	-0.099 (-0.805)	0.357*** (2.995)	0.549*** (13.522)	-0.038 (-1.137)	-0.025 (-1.613)	0.018** (1.979)
0.95	0.022 (0.006)	-0.357*** (-4.122)	-0.261*** (-3.003)	-0.107 (-1.214)	0.369*** (3.003)	0.534*** (10.541)	-0.059 (-0.927)	-0.014 (-1.540)	0.022** (1.996)

Note: The table provides the results of quantile estimation. The t statistics are between brackets. *, ** and *** show 10%, 5% and 1% significance levels respectively. Source: Author Estimations.

the range of quantiles 0.05–0.20 indicating bearish market conditions, the impact of green energy stock is insignificant, whereas in bullish market conditions, i.e., at the quantiles of 0.30–0.95, its impact is significant and positive.

In the short-run dynamics scenario, the findings reveal that earlier values of GB have a positive and significant effect on the present value of GB at all quantiles. The contemporary variations in GP are found to impact GB positively at the lower range of quantiles (0.05–0.20) only. Similarly, the results from the short-run scenario indicate that present GB variations are negatively and significantly affected by present changes in EP over the quantile range (0.05–0.60). Contrarily, the past and current changes of green energy stock positively and significantly impact GB's past and current changes at all quantiles except (0.05–0.10). Thus, the overall QARDL model concludes that GP and EP have a significantly positive impact from lower to medium quantiles both in the long and short run, while green energy stock is found to have a significant and positive impact from medium to upper quantiles both in the short run and long run.

To observe the parameter constancy (linearity) of the estimated parameters, the Wald test is applied, and its results are given in Table 5.

As per the estimation, the test's null hypothesis (H_0) of the symmetric and linear relationship between the variables is not accepted at a 1% significance level. Thus it can be inferred that the parameters are asymmetric and non-linear in various quantiles in the long run globally. In the same way, the null hypothesis which considers the linearity of short term increasing impact of the previous values of GB over the estimated quantiles. In addition, the test results indicate that green energy stock has a non-linear asymmetric effect on GB as the H_0 of parameter linearity is rejected overall quantiles. Contrarily, GP and EP have a symmetric and linear impact on GB in the short run.

Table 5. Wald Test Results for the constancy of parameters.

Variables	Wald-statistics [P-Value]
P	13.581*** [0.000]
β_{GP}	34.634*** [0.000]
β_{EP}	6.982*** [0.000]
β_{CLEAN}	15.623*** [0.000]
φ_1	8.201*** [0.000]
ω_0	0.864 [0.341]
λ_0	1.019 [0.164]
θ_0	8.659*** [0.000]

The square brackets contain the p -values. *, ** and *** show significance at the 10%, 5% and 1% level respectively.

Source: Author's own Estimations.

The results of the Granger causality test are provided in [Table 6](#). A bidirectional causal association is found among all the considered variables overall quantiles, i.e. (0.05–0.95). The findings indicate that contemporary and earlier realisations of GP, EP, and CLEAN are better predictors of GB and vice versa.

4.1. Discussion

The findings of negative GP showing a downward trended long-term relation of GP and GB signifies that the green bond market faces more difficulty with the rise in gold prices. This is a fascinating finding, showing that gold's safe-haven attributes give investors diversification opportunities during all market conditions, particularly more significantly during bullish market situations. The finding seems intuitively reasonable because the goals of investing in gold and green bonds are so dissimilar. Gold investors are commonly referred to as 'gold bugs', who invest in gold as a safe haven. On the other hand, Green bond investors are drawn to the sector because it offers a combination of sustainability and fixed income. This finding adds this work to the domain of earlier research (Kocaarslan & Soytaş, 2019) but contrasts with (Dutta et al., 2021), and therefore, it makes a significant contribution to the existing literature.

Considering the relationship between EP and GB, findings seems credible because high oil prices stifle investments in green bonds in the long run due to the increasing opportunity cost of energy market investment. On one hand, rising oil prices influence economic activities in a significantly negative way because of their negative impact on household income and the cost of production of the firms. Increases in production costs diminish profitability, which has a negative impact on future and present cash flows. A spike in oil prices, on the other hand, causes price inflation in worldwide markets. Augmented inflation pressure has a major impact on the cash flow discount rate, resulting in lower stock values (Kocaarslan & Soytaş, 2019). This throws off the balance of the economy and, as a result, makes the investment climate

Table 6. Quantile Granger causality test results.

Quantiles	$\Delta GB_t \downarrow \Delta GP_t$	$\Delta GP_t \downarrow \Delta GB_t$	$\Delta GB_t \downarrow \Delta EP_t$	$\Delta EP_t \downarrow \Delta GB_t$	$\Delta GB_t \downarrow \Delta CLEAN_t$	$\Delta CLEAN_t \downarrow \Delta GB_t$
[0.05–0.95]	0.000	0.000	0.000	0.000	0.000	0.000
0.05	0.000	0.000	0.000	0.000	0.000	0.000
0.10	0.000	0.000	0.000	0.000	0.000	0.000
0.20	0.000	0.000	0.000	0.000	0.000	0.000
0.30	0.000	0.000	0.000	0.000	0.000	0.000
0.40	0.000	0.000	0.000	0.000	0.000	0.000
0.50	0.000	0.000	0.000	0.000	0.000	0.000
0.60	0.000	0.000	0.000	0.000	0.000	0.000
0.70	0.000	0.000	0.000	0.000	0.000	0.000
0.80	0.000	0.000	0.000	0.000	0.000	0.000
0.90	0.000	0.000	0.000	0.000	0.000	0.000
0.95	0.000	0.000	0.000	0.000	0.000	0.000

Source: Authors Estimation.

worse. When looking at the economic process, in the long run, it is clear that a rise in oil prices negatively impacts green bond values, contrary to common assumptions. The finding of our study is in line with (Kanamura, 2020; Saeed et al., 2020; Kocaarslan & Soytaş, 2019) but in contrast with (Dutta et al., 2021; Azhgaliyeva et al., 2021; Lee et al., 2021).

Considering the relationship between CLEAN and GB, the findings are consistent with the findings of Liu et al. (2021) but in contrast to Nguyen et al. (2021) and Reboredo (2018), who found that green bond markets are weakly linked with clean energy markets. Thus it indicates that the green bond market and green energy stocks experience booms and bursts together, implying that an increase in green energy stock prices attract an inflow of capital and helps in the expansion of the scale of investment, which further leads to a rise in the more investment in green bonds (Liu et al., 2021). Lastly, the outcome of green energy stock and GB contrasts with the finding of Dutta et al. (2021), who observed the opposite phenomenon while studying green bonds and green stock indices relationship for India.

5. Conclusion and policy recommendations

Because of its significant role in funding environment-friendly projects by limiting the adverse consequences of climate change, the GB market has achieved significant development in terms of its benefits for stakeholders as well as for governments over the past decade. However, research about the interaction of this market with other environmental and financial aspects is still scarce. To fill in this gap, this study investigates the non-linear linkages between GB and environmental and financial variables such as oil prices, gold prices, and the green (clean) energy stocks over the period from 01-01-2010 to 30-06-2021. To achieve this purpose, Quantile Autoregressive Distributed Lagged (QARDL) approach developed by Cho et al. (2015) is applied in this study. The reason for selecting this analysis is its property to check the effect of a range of quantiles of oil price, gold price, and green energy stock green bond markets, thus providing a more comprehensive explanation of the dependence of green bond markets and oil price, gold price and green energy stocks harmonised to conventional techniques such as quantile regression or OLS. We also examined causality

in quantiles, as described by Troster (2018), to see a causal relationship between gold, oil, green energy stock, green bond markets, and vice versa.

The QARDL results reveal that the error correction value is significant for all quantiles, with the predicted negative sign suggesting that there is a considerable reversion towards the long-run relationship between the associated variables and the GB market. Specifically, the findings suggested that gold prices decrease green bonds in the long run on every quantile. But, an increase in oil price decrease green bonds at lower to middle quantiles. It suggests that the increase in oil and gold prices causes a decline in green bond investments in the long run. As for green energy stocks, it is implied from the results that an increase in green energy stock brings a positive impact on green bond investment in the long run. Furthermore, the results of the short-term dynamic established an asymmetric impact of oil price, gold price, and green energy stocks on GBs in the short run. In addition, the outcomes of the causal relationship given by the granger causality test in quantiles reveal a bidirectional causality link between oil price, gold price, and green energy stocks on green bonds in Turkey.

The GB market has made significant progress, but there are still prospects for development and improvement. Our findings have several significant implications for shareholders and policymakers in this context. To achieve additional market expansion, particularly in the green energy sector, numerous stakeholders must work together. By implementing climate-related green bond standards and providing supportive policies to foster the clean energy industry's development, policymakers can help to increase the availability of GBs. To promote GBs, public financial institutions can demonstrate issuance and capacity growth. Institutional investors can contribute by matching the investment goals with sustainability concerns over the long run. Other parties, such as financial institutions, retail investors, and rating agencies, can help develop the GB market and accelerate the global energy transformation.

The finding of a positive relationship between GB and green energy stocks suggests that there is no hedging between long positions in GBs clean energy stocks because both assets have movement in the same direction at different market conditions. It is critical to consider systemic risks when developing the best portfolio investing plan, as these risks might reduce diversification returns. When constructing their investment portfolio strategies, investors should be aware of the non-linear causal positive relationship between GBs and green energy assets. Because asset correlation is the most critical aspect in developing a risk-diversifying portfolio, an increase in asset association can result in a considerable drop in the original portfolio's ability to spread risks. A considerable increase in the correlation between the GB and the green energy stock market, especially after a crisis, would greatly raise the total portfolio risk, necessitating a rapid portfolio solution adjustments of GBs and equivalent assets.

Green bonds are negatively linked to world gold prices, indicating that gold is safe for green bonds in harsh market situations. Gold prices are viewed as a more effective hedge for green bonds. Hedging indicates that while the price of an item rises, it lowers the hedge asset price. In general, a stock's price rises following a severe negative shock. The existence of a hedge, on the other hand, works against haven in the long run. Investors must comprehend and thoroughly evaluate the linkage dynamics between different financial stocks for optimum advantages from increased portfolio

diversification obtained through investment selections. To improve their hedging performance, investors must be able to accurately foresee varying trends in these critical commodities. For better protection and hedging approaches and well-informed asset allocation considerations, they must be fully aware of the shifting dynamics in the links between the commodities and equities returns. Finally, oil price fluctuations signal a shift in macroeconomic conditions, necessitating government intervention to encourage more green investment at a time when oil prices are low. Following a drop in oil prices, while the green investment does provide favourable incentives, policy-makers should rethink and reinterpret their strategy to promote the green bond investment. Government authorities should increase their subsidies for green bonds investment and launch huge public awareness campaigns regarding its beneficial impacts on environmental quality.

6. Limitations

Similar to other research studies, the current study also possesses certain limitations, which provide an avenue of exploration for future researchers. Firstly, the availability of the data is the prime limitation. Though for the application of the statistical technique, daily data was utilised. Nevertheless, the higher the data, the higher is the predictive ability. Secondly, the current study analyzes the data of Turkey only, whereas exploration of other countries could also expand the literature. Thirdly, the present study is a time series, and more contributions to the literature can be made through the studies following panel methodologies. Lastly, the application of QARDL only establishes the linkage with the quantiles of the dependent variable, whereas applying techniques that link the quantiles of the dependent variable with the quantiles of independent variables can lead to more insightful findings.

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