Dynamic Relationship Among Green Bonds and Commodities in Response to Geopolitics and Pandemic Policies

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Abstract. This study aims to examine the connection among green bonds and global commodity markets, with particular attention on the occurrence of price spillover and return spillover during the Covid-19 pandemic and the Russia-Ukraine conflict situations. The study uses daily data from January 1, 2018 to December 31, 2022 from the global green bond index and commodities index, To analyze the connection between the green bond market and the commodities market and the price spillover and return spillover among these markets, the Time Varying Parameter Vector Autoregression (TVP-VAR) model is used. The results of the study show that there is a connection between green bond prices and commodity prices, especially during the Covid 19 Pandemic and the conflict between Russia and Ukraine. Both events triggered significant fluctuations in financial markets due to the increase in the price of several commodities. Agricultural and energy commodities become the largest price transmitter spillover to green bond prices and other commodities in the observation, while oil and green bonds become the largest price receiver spillover from other commodities in the financial market. Energy and oil commodities become the dominant return transmission spillover to green bond returns and commodity returns. On the other hand, gold and green bond commodities are the dominant return receiver spillovers from other commodity markets. This research provides a practical contribution for investors to make green bonds as an investment instrument. For policy makers, this research is the basis for issuing rules related to green bond development

Keywords: Green Bonds, Dynamic Connection, Spillover, Commodities, Geopolitics.

1 Introduction

Green bonds have experienced rapid growth over the past two decades. Ever since their first issuance in 2007, green bonds have been an innovative form of financing where

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the proceeds are utilized specifically for projects aimed at addressing the consequences of global warming and efforts to reduce it [1]. Green bonds were first issued as climate awareness bonds by the European Investment Bank (EIB). The EIB has issued GSS bonds of up to EUR 2.2 trillion until mid-2022, and the World Bank issued green bonds in 2008. Over 50 countries have issued green bonds since their inception. It's interesting to note that there was a significant increase in green bond issuance from 0.6% to 8.9% of the total bonds issued until 2022. The motive for investing in green bonds made by institutional investors is driven by pro-environmental motives as a result of the implementation of policies by regulators [2].

The investment sector has experienced pressure due to the pandemic because many people prefer to keep their money in cash compared to investing in financial assets. The COVID-19 pandemic has triggered price movements of several commodities, the price of petroleum was observed to experience a significant decline in March and April 2020, or after the World Health Organization (WHO) announced a Pandemic due to the COVID-19 virus in March 2020 and was followed by a regional closure policy by many countries in the world as an effort to prevent the spread. Commodities such as gold experienced a decline in prices around March 2020, but in the following month, the price of gold experienced a very significant strengthening and increase as a result of the depreciation of the US dollar exchange rate and lower interest rates. Prices of agricultural and food commodities tend to be stable because food is a source of basic human needs that must still be consumed, but price increases for agricultural and food products are found in several regions such as South Asia, Africa, and Latin America [3]. Different with previous research above, others found that in the short term or the first quarter of 2020, the correlation between green bond returns and financial market returns was weak. This shows a signal to diversify assets in the short term [4]. The global spread of the coronavirus triggered high volatility, during the COVID-19 Pandemic period, green bonds became the recipient of the shock spillover together with energy assets such as wind and carbon [5]. Other research shows that during the COVID-19 Pandemic, including green bonds and conventional investments is a form of diversification strategy in the short term [6].

Geopolitical policies such as imposing economic sanctions on a country, political instability, and war can impact a country's economy either directly or indirectly. No country in the world does not depend on other countries economically. The conflict between Russia and Ukraine is one example of a geopolitical policy outcome. On February 24, 2022, Russian troops attacked Ukraine. The impact of this event was an increase in commodity and energy prices, a food security crisis, and a disruption of the supply chain [7]. Russia and Ukraine are countries that have national products in the form of energy commodities that are exported to many countries. The conflicts that occur certainly have an impact on the scarcity of energy commodities and affect commodity prices at the international level. The Russia-Ukraine conflict has triggered an increase in the level of uncertainty and caused spillover effects, although the impact is not as great as in the COVID-19 Pandemic situation [8]. A strong connection between the green bonds market and financial asset markets occurs in the short-term period, but not in the medium and long-term periods. In other words, the connection between the global green bonds market and financial assets such as the global stock market, energy stock

market, oil market, treasury bonds, corporate bonds, and currency market is affected by the time horizon [9].

Ukraine is the largest wheat-producing country and a major supplier to countries in Europe and the world. A positive correlation was found between green bonds and wheat commodities. The research conducted was in the period of the COVID-19 pandemic [10]. Previous research did not find a significant correlation between green bonds and wheat as an agricultural commodity, in other words, green bonds have diversifications benefits against [11]. However, unlike wheat, corn, which is an agricultural commodity as well as a grain commodity, does not correlate with green bonds [10].

Ukraine is a producer of several industrial metals, such as iron, steel, manganese, aluminium and several other types of metals. Russia's economic embargo against Ukraine has certainly had an impact on the metal industry in Ukraine. There is a connection between green bonds and industrial metals, such as steel, aluminum, copper and climate bonds. This is shown by the risk transmission from industrial metals to green bonds [12]. Other research shows a connection between green bonds and precious metals such as copper, gold and silver [10] [13].

This study shows that green bond returns have a very strong positive correlation with gold commodity returns, but on the other hand, green bond returns have a very strong negative correlation with heating oil returns [10]. Other study reveals that green bonds have a role as a receiver as well as a transmitter of shock for gold and silver commodities [13]. There is a connection between green bonds and gold, both in the short and long term. In contrast to previous research, this study reveals the role of green bonds as a spillover transmitter to the gold commodity [14] [15]. Other research reveals different results, where no connection was found between green bonds issued in China and the gold commodity [16].

Crude oil is one of the commodities that has an important role and is considered in making investment decisions. There is a positive relationship between oil commodities and green bonds, but during the global pandemic due to COVID-19, the relationship between oil commodities and green bonds is negative. This shows that commodities cannot be used as a hedging instrument [16]. Other research shows that there is a weak relationship between green bonds and crude oil, so it can be explained that green bonds have diversification benefits over oil commodities [17].

The study aims to: 1) analyze the price and return connections between green bonds and globally traded commodity markets and 2) analyze the existence of price spillover and return spillover between the green bond market and the commodity markets of grains, energy commodities, metal industry, gold commodities, petroleum, and agricultural commodities. The observation range was carried out during the COVID-19 pandemic and the conflict between Russia and Ukraine. In contrast to previous studies, this study uses agricultural commodity markets that trade agricultural products, both real commodity trading and futures trading. This research is expected to contribute theoretically through empirical evidence of the connection between green bonds and commodity markets during times of uncertainty such as pandemics and conflicts between countries. This study is expected to be an input for investors when making investment decisions, namely diversification and hedging strategies. In addition, for policymakers, this research can be used as a basis for decision-making for the development of green bonds

in the future. This research is the first to examine the interaction between price and return of green bonds with commodities of grain, metal industry, energy, and agriculture. This study is also the first to use agricultural commodity variables and examine the interaction between these commodities with green bonds and other commodities, especially associated with the conditions of the COVID-19 Pandemic and the Russia-Ukraine conflict.

2 Data and Methodology

2.1 Data Description

This study uses daily closing price data of the green bond market and commodity market downloaded through eikon refinitiv. The data sampling period was in the range of December 31, 2017 to December 31, 2022 where there were two episodes of important events, namely the initial period of the spread of the COVID-19 outbreak and the beginning of the Russia-Ukraine conflict, with a total of 1,309 observations. The data used are daily data from the following indices as follows: Solactive Global Green Bond (SOLGREEN) is a global green bond market index, DJ Commodity Grain (DJCIGR) is a commodity grain market index, including wheat, soybeans, rice and others. DJ Commodity Energy (DJCIEN) is an index of energy commodity markets including coal, natural gas and others. DJ Commodity Industrial Metal (DJCIIM) is an index of iron, steel, copper and other commodities. DJ Community Gold (DJCIGC) is a gold commodity index. ICE Europe Brent Crude Electronic Energy Future (BRENT) is a petroleum market trading index and S-Net ITG Agriculture (AGRI) is an agricultural commodity market index. The description of the data is provided as follows:

Table 1. Data Set Description

Index	Abbreviation	Source	Observations
Solactive Green Bond Index	SOLGREEN	Refinitiv	1,309
DJ Commodity Grain	DJCIGR	Refinitiv	1,309
DJ Commodity Energy	DJCIEN	Refinitiv	1,309
DJ Commodity Industrial Metal	DJCIIM	Refinitiv	1,309
DJ Commodity Gold	DJCIGC	Refinitiv	1,309
ICE Europe Brent Crude Electronic Energy Future	BRENT	Refinitiv	1,309
S-Net ITG Agriculture USD Index	AGRI	Refinitiv	1,309

Source: Dow Jones

The reason for using the Solactive Green Bonds (SOLGREEN) index is because this index is a green bond index that has the longest history compared to other green bond

indexes. Besides, this index consists of green bonds that have a green label that refers to the rules of the climate bonds initiative (CBI). In addition, this index is a global green bonds index. Throughout the occurrence of trading transactions, SOLGREEN is an index that having good performance. The selection of the Dow Jones Commodities Index is based on the fact that it consists of a diversified range of commodities. This index is widely used by mutual funds for performance comparison before making investment decision.

The variables use in this study are price (P_t) of green bonds and commodities at time t and; return (R_t) of green bonds and commodities at time t where to obtain this variable the calculation is done using the formula $R_t = \frac{P_t - P_{t-1}}{P_{t-1}}$ where R_t is the rate of return on investment in the financial asset market which is the difference from the closing price of the day t (P_t) less the closing price of the day t-1 (P_{t-1}) divided by closing price t-1 (P_{t-1}).

2.2 Time Varying Parameter Vector Autoregression (TVP-VAR)

This study used Time Varying Parameter Vector Autoregression (TPV-VAR) which is an extension of the Diebold & Yilmaz measurement method [18, 19] namely the measurement of connectedness through forecasting error variance decomposition vector autoregression (VAR) models. This measurement examines spillovers from or to financial markets. The advantages of TVP-VAR are, 1) no arbitrary rolling window settings are required, 2) no observations are lost and 3) are not sensitive to outliers. TPV-VAR is used to measure price connectedness and return spillover among variables [20]. TVP-VAR is a method that provides more accurate results than other methods that use rolling window evaluation. This method ignores the assumption of heterogeneity and assumes market participants have the same preferences, expectations and risk aversion.

This method begins with the formation of equations based on the Bayesian Information Criterion (BIC) which is formulated mathematically as:

$$y_t = B_t y_{t-1} + \varepsilon_t \qquad \varepsilon_t \sim N(0, \Sigma_t) \tag{1}$$

$$vec(B_t) = vecB_{t-1} + v_t \qquad v_t \sim N(0, S_t) \tag{2}$$

where y_t, y_{t-1} and ε_t is dimension vector of K x 1 and B_t and Σ_t are dimension matrix of $vec(B_t)$ and v_t is $K^2 x\ 1$ dimension vector, where S_t is $K^2 x\ K^2$ dimension matrix. Decomposition stage *forecast error variance* on horizon H:

$$\theta_{jk}(H) = \frac{\sigma_{kk}^{-1} \sum_{h=0}^{H} ((\Psi_h \Sigma)_{jk})^2}{\sum_{h=0}^{H} (\Psi_h \Sigma \Psi_h^{'})_{jj}} \tag{3}$$

where Σ is *variance matrix* for *error vector* $\mathcal{E}$, σ_{kk} is the standard deviation of the *error term* for the equation *kth* and e_i is a *selection vector*. Further $\theta_{jk}(H)$ rewritten to:

$$\tilde{\theta}_{jk}(H) = \frac{\theta_{jk}(H)}{\sum_{k=1}^{n} \theta_{jk} H} \tag{4}$$

where $\tilde{\theta}_{jk}(H)$ is *the directional spillover* of the variable *k* to *j* on horizon H. The entire *spillover* is written back as:

$$(C_H) = 100\ x\ \frac{\sum_{k=1,j\neq k}^{n} \tilde{\theta}_{jkH}}{\sum_{j,k=1}^{n} \tilde{\theta}_{jkH}} \quad (5)$$

TO spillover *measurement* measures *directional spillover* of variables *j* to all indexes:

$$(C_{H_{\leftarrow j}}) = 100\ x\ \frac{\sum_{k=1,j\neq k}^{n} \tilde{\theta}_{jkH}}{\sum_{j,k=1}^{n} \tilde{\theta}_{jkH}} \quad (6)$$

Measurement of spillover FROM as directional measurement of spillover to variable *j*:

$$(C_{H_{j\leftarrow}}) = 100\ x\ \frac{\sum_{k=1,j\neq k}^{n} \tilde{\theta}_{jkH}}{\sum_{j,k=1}^{n} \tilde{\theta}_{jkH}} \quad (7)$$

Measurement *of net directional spillover* from variables *j* is:

$$(C_H)_j = (C_{H_{\leftarrow j}}) - (C_{H_{j\leftarrow}}) \quad (8)$$

Thus *net pairwise spillover* between indexes *j* and *k* calculated as follows:

$$(C_H)_{jk} = 100\ x\ \frac{\tilde{\theta}_{kjH} - \tilde{\theta}_{jkH}}{n} \quad (9)$$

FROM is part of the *shock* received from other indices that are in *the total variance of the forecast error* for each index. In addition, FROM is used to measure the extent to which *shocks* emanating from other indices affect the variability of *forecast error* of each index. TO is a description of *the shock* transmitted from a particular index to the variance of the *forecast error* of each index. TO is used to measure the effect of the devolved effect of one index on the *forecast error variance of* another index. The difference between TO (formula 6) and FROM (formula 7) results in NET SPILLOVER (formula 8). TO and FROM also show the role of assets as NET RECEIVER or NET TRANSMITTER for *shocks* that occur in the financial system.

3 Empirical Results

3.1 Descriptive Statistic

Based on descriptive statistics, the mean value of green bond price (SOLAGREEN) was USD 1,018.7, while the mean value of cereals or grains price (DJICGR) throughout the observation period was USD 228.8. The Mean value of Energy commodities (DJICEN), produced by many countries in Eastern Europe such as Russia and Ukraine, is valued at USD 105.97. In contrast, the mean of trading price of metal industry commodities (DJICIM) traded in commodities market throughout the observation period is

valued at USD 144.68. The mean value of precious metal commodities, namely gold (DJCIGC), where traded on the commodity market, is USD 556.7. Petroleum commodity (BRENT) is a commodity that has an essential role in the world economy and is one of the many macroeconomic indicators. The average price of BRENT oil is USD 69.73 per barrel or a measure of oil volume. The average value of agricultural commodity prices (AGRI) is USD 6,293. The price of agricultural commodities is a commodity that has the lowest standard deviation, which is 1,472.75. That is, compared to other asset investments in this study, agricultural commodities are less volatile investments than the other investments in this study. Descriptive statistics on data are described in Table 2:

Table 2. Descriptive Statistic

Obs=1309	SOLAGREEN	DJICGR	DJICEN	DJICIM	DJICGC	BRENT	AGRI
Panel A. Price							
MEAN	1018.7	228.8	105.97	144.68	556.7	69.73	6293
MEDIAN	1021.5	191.7	98.92	135.87	592.7	68.57	5551
MAXIMUM	1160.6	387.4	210.00	237.30	714.6	127.98	9994
MINIMUM	775.9	160.0	30.06	94.72	408.8	19.33	3290
Std Dev	84.04347	62.09974	34.86937	30.54152	85.35897	19.82295	1472.25
Sum	1332516	299219.3	138602.6	189244	728118.5	728118.5	8231295
Panel B. Return							
MEAN	-0.0001243	0.0005411	0.0006373	0.0002305	0.000299	0.000578	0.0004307
MEDIAN	0.0000000	0.0002568	0.0014689	0.0002946	0.0002624	0.002035	0.0005515
MAXIMUM	0.0242912	0.0643445	0.158954	0.0580472	0.0575995	0.210186	0.0803946
MINIMUM	-0.0263329	-0.0626800	-0.2601345	-0.0422535	-0.0493002	-0.244036	-0.1074157
Std Dev	0.004091331	0.0123221	0.0252274	0.0115853	0.009448	0.027545	0.0135215
Sum	-0.1626091	0.7077141	0.833565	0.3015431	0.3911549	0.7559634	0.5633884

Source: Output R Studio

Most of the daily mean returns from the data used are positive, except for the mean return of green bonds, which has a negative value. One of the policies taken by policymakers in the world to overcome the economic recession caused by the pandemic is to reduce the lending interest rate, which is one of the reasons for the decline in green bond returns. The highest rate of return was found in BRENT at 0.210186, while the lowest rate of return was found in energy commodities (DJICEN) at -0.2601345. The highest average return was found in energy commodities at 0.0006373, and the lowest average return was found in green bonds at -0.0001243. The standard deviation of the return of the green bond index is the smallest number compared to the standard deviation return of the commodity market index, which is 0.004091331. This shows low variability or distribution and indicates that green bond investment is a less volatile investment than the other six commodity indices. Furthermore, a stationary test was carried out using the augmented dickey fuller test, the results showed that all data were stationary, so they were suitable for further testing.

3.2 Results and Disscussion

Dynamic Total Connectedness – Price. The following are the results of TVP-VAR processing with a connectedness approach. The plot in Figure 1 is the closing price of the green bond index and the commodity market index from 2018 to 2022. Some events are the focus of attention that have an impact on the global economy, namely the beginning of the COVID-19 pandemic and the beginning of the Russian invasion of Ukraine. The plot shows an increase in the connection be-tween green bonds and commodities from the end of December 2019 to early January 2020 and reached its peak in early March 2020 when the spread of the virus was wider, and the addition of cases was very significant, indicating by a connection index value of 57.52%. The initial of the COVID-19 case led to lockdowns in various countries, causing trade and economies worldwide to come to a halt or slow down. This led to an increase in prices due to product scarcity, especially for essential items such as food and agricultural products.

The distribution of the value of the price connectedness index between green bonds and commodity markets varies where from the plot it can be seen that the lowest point is at the price connectedness index value of 37.47% which occurred in April 2021 the highest point is 58.43% which occurred in March 2022. The greater difference between the highest and lowest values indicates that there are strongly interconnected markets. The strong connection between assets in the study indicates that the connection between assets in the market not only reacts to events related to the green bond and commodity markets but also to external factors.

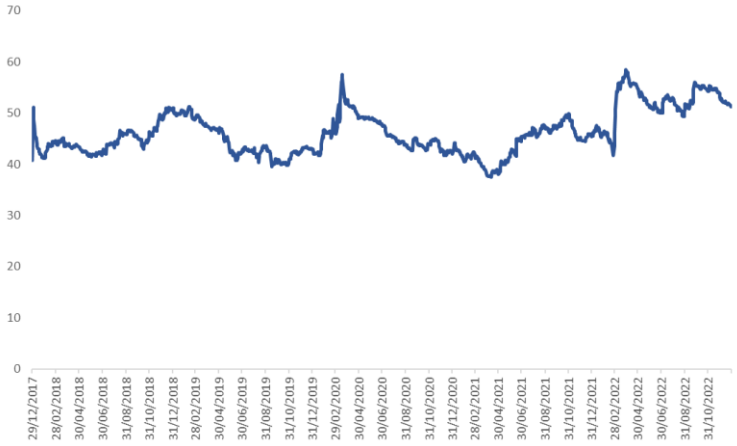

Fig. 1. Dynamic connectedness among commodities index - price

The increasing prices of agricultural commodities, which are the source of staple foods, affect the prices of other commodities. In addition to agricultural commodities, energy commodities consist of natural gas, gasoline, oil, heating oil, and electricity. These commodities have an important role in human life because, in addition to being used in daily human life, they are also needed for production, so any price movements from

these commodities will affect other commodities. In addition, the pandemic that occurred has changed human habits, which usually work in the office or outside where humans live, due to restrictions on activities that are imposed, making humans adapt to continue working, schooling, and others from home. For this reason, humans need electrical energy, which is part of the energy commodity. In other words, during the beginning of the COVID-19 Pandemic and the beginning of the Russian invasion of Ukraine, there was a strong price connection between green bond prices and commodity prices.

Dynamic Total Connectedness – Return. Based on the Total Connectedness Index (TCI) graph, there is a highly fluctuating pattern. The higher the TCI value, the stronger the relationship between green bond returns and commodities. A high TCI value also indicates an increase in the risk of investing in financial assets. The highest point in Figure 2 where the TCI index is 76.52% occurred in the 2018 period. In this year, several events affected the investment world, including the decline in the S&P 500 index and the Dow Jones Industrial Index by up to 10%. In addition, in 2018, the Federal Reserve raised the lending rate, so this event had an im-pact on the return on fixed-income investments. The trade war between the United States and China drove investor sentiment, and not to forget the impact of the Brexit decision also influenced the global investment world. In the commodity market, espe-cially oil commodities, the economic sanctions imposed on Iran and the decline in oil production in Venezuela put pressure on world oil prices. In 2018, China restricted the production of metals such as aluminum and steel to reduce carbon emissions and this had an impact on metal commodity prices. Overall in 2018, fluctuations in the green bond and commodity markets were triggered by geopolitical decisions, interest rate hikes, and movements in commodity supply and demand curves. Conditions at the beginning of 2018 showed a strong relationship between returns in the green bond market and commodity markets, but this condition tended to decline and eventually flat until entering 2020.

Fig. 2. Dynamic connectedness among commodities index - return

The connection strengthened again after the beginning of the spread of COVID-19, namely in January 2020. The total connectedness index at that time reached a total of 56.07%, the COVID-19 pandemic has made the return connection in the green bond market and the commodity market strengthen again. The increase in gold commodity prices and oil prices also affects the prices of other commodities in the market and drives the movement of commodity returns. Green bonds and gold commodities are investments that have the same characteristics, which are both long-term investments.

Mid-February 2022 when the Russian President announced his invasion of Ukraine and was greeted with an increase in oil prices. It takes time to respond to the volatility of returns from each commodity to then spread to other commodities. So far, because the Russia-Ukraine conflict is continuing, investors are still making adjustments in determining their investment strategy. The results of data processing also indicate that there is a strong connection between returns in the green bond market and the commodity market throughout 2022 where the peak occurred in October 2022 with a Total Connected Index value of 50.99%. Some events that affect the connection between green bonds and commodities are the decline in crude oil prices as a result of the decision of oil exporting countries (OPEC) to reduce oil supply, the Fed's interest rate hike, and the imposition of economic sanctions on Russia as a result of Russia's invasion of Ukraine.

Price Spillover. Using the index values in

, we analyze both transmitted and received spillovers from the green bond market to the commodity market, and vice versa. Panel A, the connectedness matrix is divided into two: diagonal values and off-diagonal values. Diagonal values show the increase in the value of variances due to the entity itself, while off-diagonal values show the contribution of the increase in the value of variances caused by other entities. This study uses the assumption of 200-day rolling windows, this assumption is closest to the actual evolution of the Total Connected Index (TCI) used in the TVP-VAR model [18].

Throughout the observation period, the total connectedness in the system is 46% or there is a large enough price connection between the green bond price index and the commodities price index. This shows that when there is a price change in one commodity market or green bond market, it will change the price in other commodity markets and green bonds. Crude oil commodity (BRENT) has the largest direct FROM index value of 63.15%, this indicates that crude oil is the most vulnerable commodity to receive shocks from other commodities, followed by energy commodities (DJICEN) with a TCI index value of 60.32% and agricultural commodities (AGRI) with a TCI index value of 47.80%. Conversely, green bonds are the least vulnerable commodities to receive shocks originating from other commodities, this is indicated by the TCI index number of 34.15%. On the other hand, DJICEN is a commodity that transmits the greatest shock (direct TO) to other commodities, with a TCI index value of 71.38% followed by AGRI with a TCI index value of 63.37% and BRENT with a TCI index value of 50.54%. As an investment instrument, green bond is a commodity that transmits the

smallest shock to the commodity market with a value of 22.06% followed by grain commodities (DJICGR) of 35.07% and gold commodities (DJICGC) worth 37.02%.

Based on the net spillover value, it is found that agricultural commodities and energy commodities are the commodities that send the highest price spillover transmission to other commodities throughout the observation period with an index value of 15.47% and 11.06% respectively. Crude oil commodity is the commodity that receives the highest price spillover transmission of 12.61% followed by green bonds with an index value of 12.09%. This finding supports the findings of previous research which states that green bonds are investment instruments that tend to be recipients of price spillover transmission from other financial assets [5]. The reason why green bonds are more of a dominant net receiver of financial assets is because green bonds tend to have a lower level of volatility compared to other financial assets and green bonds are less liquid than similar financial assets and other financial assets [21]. In addition, green bonds are more sensitive to policies and regulations taken to overcome a problem, for example, policies related to the COVID-19 pandemic and policies related to political crises, this causes green bonds to be more likely to receive spillovers as a result of policies and regulations made [22].

Green bonds receive the largest price spillover transmission from gold commodities with an index value of 15.76% followed by metal industry commodities by 6.46% and energy commodities by 4.18%. This can show when there is a movement in the price of gold, it will be transmitted and cause changes in the price of green bonds. However, this strength is not as great as the price spillover transmission of industrial metal commodities and energy commodities. Conversely, when there is a price change in the green bond market, it will be transmitted to gold, industrial metal and agricultural commodities, with an index value of 12.80%, 5.90% and 1.52% respectively. This finding shows that price changes in the green bond market are very strongly transmitted to the gold market compared to transmission to other commodity markets.

Based on

, information is obtained that agricultural commodities are the largest net transmitter of price spillovers to other commodities, which was found in mid-March 2020. Agricultural commodities are a much-needed source of food in the world, especially when restrictions are imposed, so when periodic restrictions are announced in many countries, the demand for food increases. Humans try to maintain food supplies to survive during the pandemic, which at that time was unknown when it would end. On the other hand, the petroleum commodity became the largest net receiver of price spillover at 12.61% followed by green bonds with a value of 12.09% and industrial metal commodities at 1.97%. The lowest crude oil spillover index value was found in 2019. When examined from the data period used, crude oil prices tend to be stable. The decline and increase in crude oil prices occurred from 2020 to 2022. In the period of the COVID-19 pandemic, the price of crude oil experienced a sharp decline compared to the previous year, but in the following years, namely 2021 to 2022 or during the Russian invasion of Ukraine, the price of crude oil experienced a sharp increase. This volatility in crude oil prices affects the acceptance of spillover price transmission, in more stable price conditions, crude oil tends to act as a recipient of spillover price transmission.

Return Spillover.

Panel B shows the value of the total return connectedness index between green bonds and commodities of grain, energy, metal industry, gold metal, petroleum, and agriculture is 40%, indicating a considerable return connectedness between green bond returns and commodity returns. As an investment instrument, energy commodities have the largest TCI DIRECT TO index value with an index value of 64.27%, followed by crude oil commodities at 61.60% and agricultural commodities at 39.14%. This finding shows that when a shock occurs, energy commodities become the most dominant commodities that transmit shocks to other commodities. Conversely, energy commodities become commodities with the largest TCI DIRECT FROM index value, which is worth 56.09% in other words, energy commodities become commodities that are most vulnerable to receiving shock spillovers from other commodities. Petroleum is the second largest shock receiver with an index of 55.46%.

Table 3. Connectedness Table – TVP VAR

Panel A: Price ConnectednessB2:J26								
Obs: 1309	SOLAGREEN	DJICGR	DJICEN	DJICIM	DJICGC	BRENT	AGRI	DIRECT FROM
OLAGREEN	65.85	1.02	4.18	6.46	15.76	2.71	4.01	34.15
DJICGR	0.74	65.28	6.23	6.19	6.58	2.50	12.49	34.72
DJICEN	0.52	5.66	39.68	7.69	2.98	28.27	15.20	60.32
DJICIM	5.90	6.50	7.64	53.85	5.22	7.09	13.79	46.15
DJICGC	12.80	7.23	3.43	5.32	62.78	2.68	5.77	37.22
BRENT	0.57	4.27	36.80	7.23	2.28	36.85	12.00	63.15
AGRI	1.52	10.39	13.10	11.29	4.20	7.29	52.20	47.80
DIRECT TO	22.06	35.07	71.38	44.18	37.02	50.54	63.27	**TCI Spillover**
INCLUDING OWN	87.91	100.35	111.06	98.03	99.80	87.39	115.47	**Index (323.51/700) = 46%**
NET SPILLOVER	-12.09	0.35	11.06	-1.97	-0.20	-12.61	15.47	
Panel B: Return Connectedness								
SOLAGREEN	66.21	1.77	1.85	4.88	18.09	1.77	5.42	33.79
DJICGR	1.15	78.16	5.00	3.89	2.34	4.35	5.12	21.84
DJICEN	1.05	2.60	43.91	5.45	1.80	37.85	7.34	56.09
DJICIM	4.39	3.50	7.24	61.39	4.96	7.06	11.45	38.61
DJICGC	17.85	2.30	2.48	5.18	66.63	2.40	3.16	33.37
BRENT	1.07	2.23	38.49	5.33	1.69	44.54	6.65	55.46
AGRI	3.33	3.81	9.21	10.43	3.03	8.17	62.01	37.99
DIRECT TO	28.83	16.22	64.27	35.17	31.91	61.60	39.14	**TCI Spillover**
INCLUDING OWN	95.04	94.38	108.18	96.56	98.54	106.14	101.16	**Index (277.15/700)= 40%**
NET SPILLOVER	-4.96	-5.62	8.18	-3.44	-1.46	6.14	1.16	

Source: output TVP-VAR

Based on the findings above, show that energy commodities (DJICEN) are the largest net transmitter of return spillovers with a NET contribution value of 8.18%, followed by petroleum commodities (BRENT) with an average value of 6.14% and agricultural

commodities with a NET contribution value of 1.16%. The point where energy commodities became the most dominant return spillover transmission was found in early April 2020 or after the announcement of lockdown policies in almost all countries in the world, as an effort to reduce and stop the spread of the COVID-19 virus, namely in March 2020. In addition, in October 2022, energy commodities again became the most dominant sender of return spillover transmission. Grain commodities (DJICGR) became the dominant net receiver of return turnover with a net return spillover index value of 5.62% from green bonds and other commodities in the study, followed by green bonds at 4.96% and metal industry commodities (DJICIM) at 3.44%. In the event of a shock that causes an increase in the level of investment returns, energy commodities will be transmitted to other commodities. On the other hand, grain commodities are the dominant recipient commodities of transmission from the movement of the return rate in the commodity market and green bonds.

Green bonds received the largest transmission of return spillover from the gold commodity of 18.09%, this shows that the gold commodity transmits the price spillover to the green bond. Gold and green bonds have similarities as investment assets, which are both investments in the long term. Each has advantages that investors can take into consideration. Green bonds offer fixed income throughout the life of the green bond. Gold in the long term can be used as a hedging tool. Both investments are influenced by external factors such as monetary policy, geopolitical policy, currency exchange rate fluctuations and supply-demand. As with the relationship between bonds and gold, gold prices have a positive correlation with green bond prices and a negative correlation between gold prices and green bond returns. When green bond returns are low, investors will move their investments to gold, on the other hand, when green bond returns increase, investors prefer to invest in gold. The findings show that green bond is a net receiver of return spillover from other commodity markets in the study with a relatively small index value of -4.96%. From the above results, it can be concluded that green bonds are assets that benefit from the spillover returns contained in other assets in the financial markets. This study supports the findings of previous studies which state that green bonds are net receivers of return spillovers from shocks transmitted by other commodities [10].

During the pandemic, it was observed that both commodity prices and returns experienced a significant connection, particularly at the onset of health-related decisions. However, this connection was short-lived as the shocks in commodities caused by these policies began to affect the green bonds market. Eventually, the price and return levels stabilized and adjusted to their equilibrium points.

4 Robustness Test

Robustness tests are conducted to increase the reliability and validity of the findings of the research conducted. The purpose of the test is to confirm and convince the strength of the model used. In this study, the robustness test was conducted using the Quantile Vector Regression (QVAR) model. The difference between this model and VAR mod-

els, in general, is that this model trace endogenous random variables in various quantiles. This model offers a powerful framework for analyzing multivariate time series data.

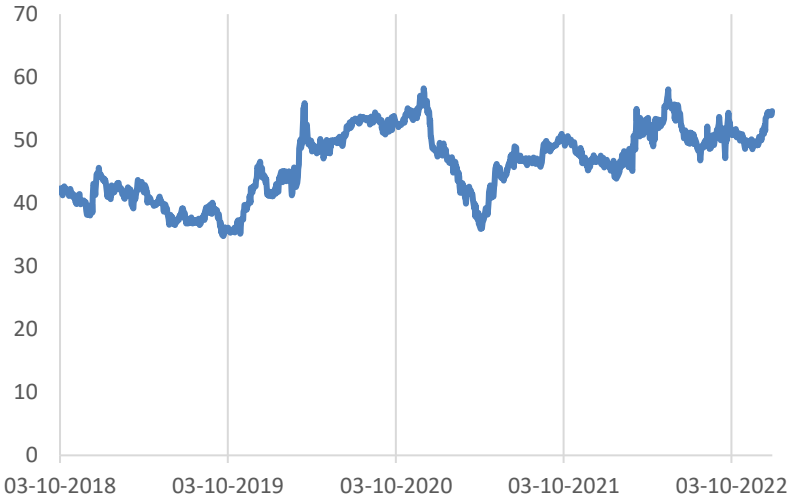

Fig. 3. Dynamic connectedness among commodities index – price (QVAR)

The results of data analysis using the QVAR model show a connection between green bond prices and commodity asset prices (Figure 3). So that any movement in commodity prices will move the price of green bonds. The con-nection between green bonds and commodity markets strengthened during the initial period of activity restrictions due to the pandemic and when Russia isolated Ukraine from trade routes as a policy related to the country's invasion of Ukraine. QVAR pro-vides results that are not much different from the results of data analysis using TVP-VAR. The higher peak of the connectedness graph indicates a strong relationship be-tween green bond prices and commodity prices. The highest point of 58, 22% was found in early 2020, when the COVID-19 outbreak spread throughout the world and the lock-down policy between countries began. This was repeated when the Russian President ordered an invasion of Ukraine and imposed other geo-political policies, again the peak connection point touched a value of 58.08%.

Using the QVAR model to analyze the connection between the level of green bond returns and commodities in the sample period obtained the same results as the analysis results using the TVP-VAR model. The highest peak indicating a return connection was found at the beginning of the pandemic in 2020 when a lockdown policy was issued to overcome the COVID-19 outbreak as well as in 2022 when geopolitical policies were taken by the President of Russia and an impact on international trade and the world economy. Having reached a peak at 46.43% in 2020, this result is not much different from the analysis conducted using the TVP VAR model. Similarly, the connection be-tween green bonds and commodity assets during political conflicts between countries

had increased, as can be seen in Figure 4. Both analyses show that the dynamic connection model above is robust.

Fig. 4. Dynamic connectedness among commodities index –return (QVAR)

The processing results using the QVAR method confirm the previous findings where data processing was carried out using TVP-VAR. Green bonds are price receivers, when there is a shock that results in changes in commodity prices, this is indicated by the spillover index value of -11.74% in Table 4. Green bonds receive the strongest shock from the gold commodity so any changes in gold prices will change the price of green bonds. Therefore, green bonds can be used as a substitute for gold commodities, in addition to both being long-term investments. Com-modities that least affect green bonds are grain commodities, any price changes in grain commodities, will not spill over green bond prices. These findings are in line with current research but use different analytical methods in data processing and analysis. The test results and data analysis using QVAR show results that are not different from the analysis results using the TVP-VAR model.

Using the QVAR method, the results of the analysis are not much different from the analysis using TVP-VAR, where green bonds are a net receiver of return spillover from commodity returns in this study. With an index number of ¬-6.69%, it shows that any change in investment returns in the commodity market will spillover to green bond returns. The commodity that provides the largest spillover transmission to green bonds is the gold commodity, with an index value of 16.62%. These results show results that are not different from the processing results using TVP-VAR.

The price connectedness index in the QVAR model shows 46% or the same result as the price connectedness index in the TVP-VAR, this result corroborates the previous results that show the relationship between commodity prices and green bond prices in

the sampling period is relatively strong. The same is found with the return connectedness index in the QVAR model showing 39%, compared to the TVP-VAR model, where the return connectedness index shows 40%. The overall results using the QVAR model show the same results as using the TVP-VAR model as an analytical tool. Based on the above findings, it can be concluded that the model used in this study is robust because it shows the same results when processing using different analytical tools.

Table 4. Connectedness Table – QVAR

Panel A: Price Connectedness								
Obs: 1309	SOLAGREEN	DJICGR	DJICEN	DJICIM	DJICGC	BRENT	AGRI	DIRECT FROM
SOLAGREEN	61.53	2.20	4.64	4.92	18.97	4.04	3.70	38.47
DJICGR	1.91	70.22	4.48	7.32	4.45	4.50	7.13	29.78
DJICEN	1.01	3.45	39.88	7.99	2.15	35.95	9.58	60.12
DJICIM	4.81	6.29	10.48	48.78	7.36	8.81	13.47	51.22
DJICGC	15.01	4.14	4.05	6.34	63.93	4.30	2.23	36.07
BRENT	1.05	3.58	36.63	7.26	2.44	40.49	8.55	59.51
AGRI	2.96	7.57	10.62	13.13	2.58	12.10	51.05	48.95
DIRECT TO	26.74	27.24	70.89	46.96	37.94	69.7	44.65	**TCI Spillover Index (324.13/700) = 46%**
INCLUDING OWN	88.26	97.46	110.77	95.74	101.88	110.19	95.71	
NET SPILLOVER	-11.74	-2.54	10.77	-4.26	1.88	10.19	-4.29	
Panel B: Return Connectedness								
SOLAGREEN	67.70	1.59	1.65	5.29	16.72	1.66	5.38	32.30
DJICGR	1.01	78.55	5.09	4.05	2.57	4.18	4.55	21.45
DJICEN	0.57	2.96	44.92	5.30	1.31	38.34	6.59	55.08
DJICIM	4.16	3.59	7.24	61.65	4.56	6.62	12.18	38.35
DJICGC	16.44	2.53	2.11	5.13	69.38	2.08	2.32	30.62
BRENT	0.61	2.55	38.95	4.87	1.14	45.47	6.41	54.53
AGRI	2.82	3.54	8.83	11.73	2.04	8.5	62.55	37.45
DIRECT TO	25.61	16.77	63.87	36.36	28.34	61.39	37.44	
INCLUDING OWN	93.31	95.32	108.79	98.01	97.72	106.86	99.99	**TCI Spillover Index (269.78/700) = 39%**
NET SPILLOVER	-6.69	-4.68	8.79	-1.99	-2.28	6.86	-0.01	

Source: output QVAR

5 Conclusion

Green bonds are issued with the aim that the proceeds collected are used only to fund sustainable projects and aim to reduce carbon emissions. Green bonds are traded in the secondary market, therefore before investing in green bonds it is important to understand the behavior of green bonds. Previous studies have analyzed the pricing side of green bonds, which is one of the factors considering investors to invest in green bonds. Green bonds are one of the financial assets that can be a tool to diversify assets, make a substitute for other financial assets that have the same characteristics, include it in the

investment portfolio, and make it a hedging tool. This study aims to analyze the dynamic relationship between green bonds and commodity markets in the situation of the COVID-19 pandemic and the Russia-Ukraine crisis. The urgency of this research is to understand the interaction of green bonds, especially with commodities in the financial market. In addition, this study aims to detect whether there are spillovers from and to the green bond market.

The results of this study show that during the shock caused by the COVID-19 pandemic and the beginning of the Russian invasion of Ukraine, there was a connection between green bonds and the commodity markets for grains, industrial metals, energy, petroleum, gold, and agricultural commodities. The connection strengthened especially at the beginning of the two events. Furthermore, the results show that there are price and return spillovers among the commodities studied in this research. Green bonds act as spillover receivers for both price changes and investment return changes in the commodity market. The gold commodity is the most influential and provides a large transmission of any changes in green bond investment prices and returns. This is because both have similarities in long-term investments.

This study is the first to analyze the dynamic relationship between green bonds and commodities that are basic human needs, such as agricultural commodities and commodities that are native to a country that is experiencing a crisis in relations with other countries. In addition, this research is the first to analyze the relationship between green bonds in situations that cause shock, namely the COVID-19 pandemic and the Russia-Ukraine crisis. The results of this study are expected to be the basis for diversifying financial assets, compiling portfolios, and making green bonds a substitute for investments that have similar characteristics.

6 Managerial Implications

As a dominant net receiver, investment in green bonds is influenced by investment in the commodity market. However, the connection between green bonds and commodities is not strong, so if there is a shock in the commodity market, it only has a small impact on green bond investments. In other words, green bonds can be a haven for investors to place their investments in these assets when a shock occurs. Global health crises and geopolitical policies in a country influence volatility in global financial markets. However, the resilience of green bonds during the Pandemic and the Russia-Ukraine conflict can serve as a sustainable investment instrument to revive the world economy. Green bonds can be used as an alternative instrument for countries in the world to revive the global economy, without having to sacrifice global emission reduction targets.

Overall, the results of this study provide significant implications not only for the field of finance, especially green finance. For interested parties, this research provides additional empirical evidence on the development of green bonds that can be used as a basis for policymaking. The development of green bonds will have an impact on the construction sector where through funding obtained from the issuance of green bonds, more and more green buildings will be built. In addition, the transportation sector will

also benefit through the development of mass transportation, so that more people have access to transportation without having to sacrifice health affected by motor vehicle pollution. The industrial sector will also develop without using energy sources derived from fossil energy combustion which has the potential to increase the amount of carbon emissions in the earth's atmosphere. Through the development of green bonds, it is expected to improve the quality of human life in the world following the sustainable development goals (SDGs).

7 Further Research

Analyzing the behavior of green bonds with other assets in financial markets other than the commodity markets studied in this research. Adding an analysis of the relationship between green bond behavior and macroeconomic conditions, using high-frequency data. Analyzing the directional relationship between the price and/or return of green bonds and other financial assets. In addition, analyzes the existence of decoupling between green bonds and other financial assets, using different analytical tools.

Since the observation period has not yet reached the stage of resolving the covid-19 pandemic case and the Russian invasion of Ukraine, so there is no best practice using the findings of this study. However, the results of this study can be an input, especially for investment managers in preparing investment portfolios and for policy makers to make regulations related to the development of green bonds. This is an input for further research on the topic of green bonds.

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